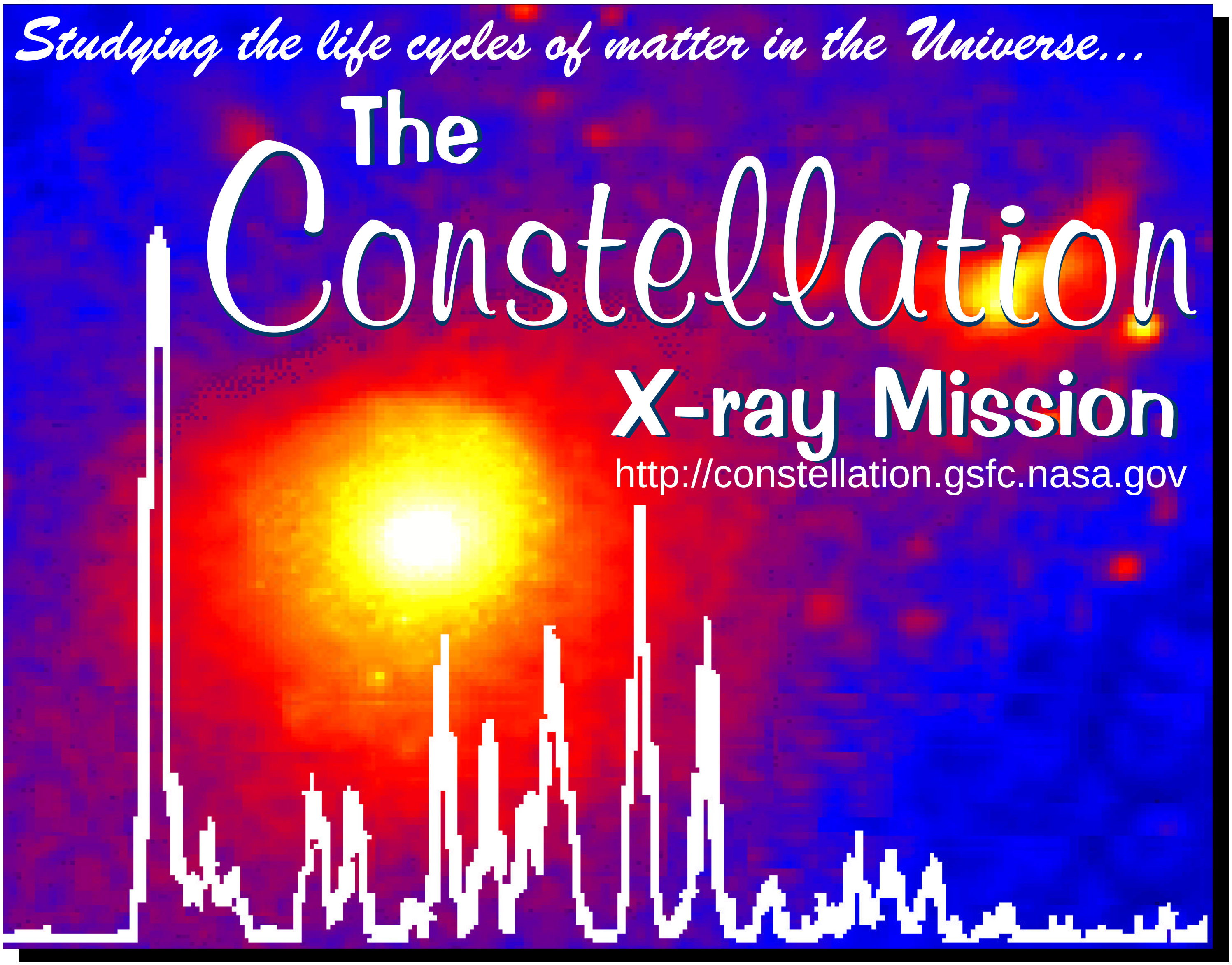
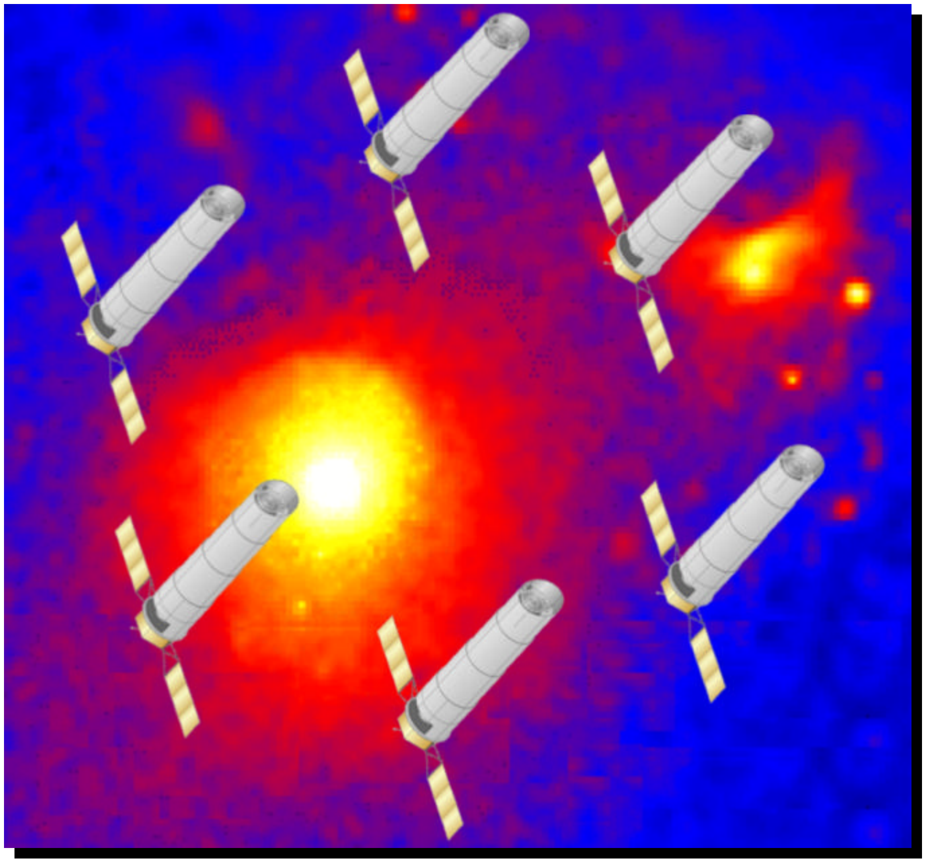
The Constellation X-ray Mission



The Constellation X-ray Mission

Studying the life cycles of matter in the Universe



Constellation-X

- Key scientific goals
  - Elemental abundances and enrichment processes throughout the Universe
  - Parameters of supermassive black holes
  - Plasma diagnostics from stars to clusters
- Mission parameters
  - Effective area: 15,000 cm^2 at 1 keV
    100 times AXAF and XMM for high resolution spectroscopy
  - Spectral resolving power: 3,000 at 6.4 keV
    5 times Astro-E calorimeter
  - Band pass: 0.25 to 40 keV
    100 times increased sensitivity at 40 keV

The Constellation X-ray Mission History

Two peer-reviewed mission concepts selected by NASA in March 1995 for possible flight during the next decade

- ***The Next Generation X-ray Observatory*** - PI: Nicholas E. White (NASA/GSFC)
- ***Large Area X-ray Spectroscopy Mission*** - PI: Harvey D. Tananbaum (SAO)

were merged into the High Throughput X-ray Spectroscopy (HTXS) Mission in late 1995.

Includes elements of a third accepted mission concept,

- ***Hard X-ray Telescope*** - PI: Paul Gorenstein

Addresses several primary and secondary NASA space science priorities (the TGSAA report) including

- Measurement of the properties of black holes of all sizes
- Study of the origin and evolution of the elements

Selected in May 1997 as a new mission to be proposed for a FY2004 new start at the Space Science Enterprise Planning *Breckenridge* Workshop.

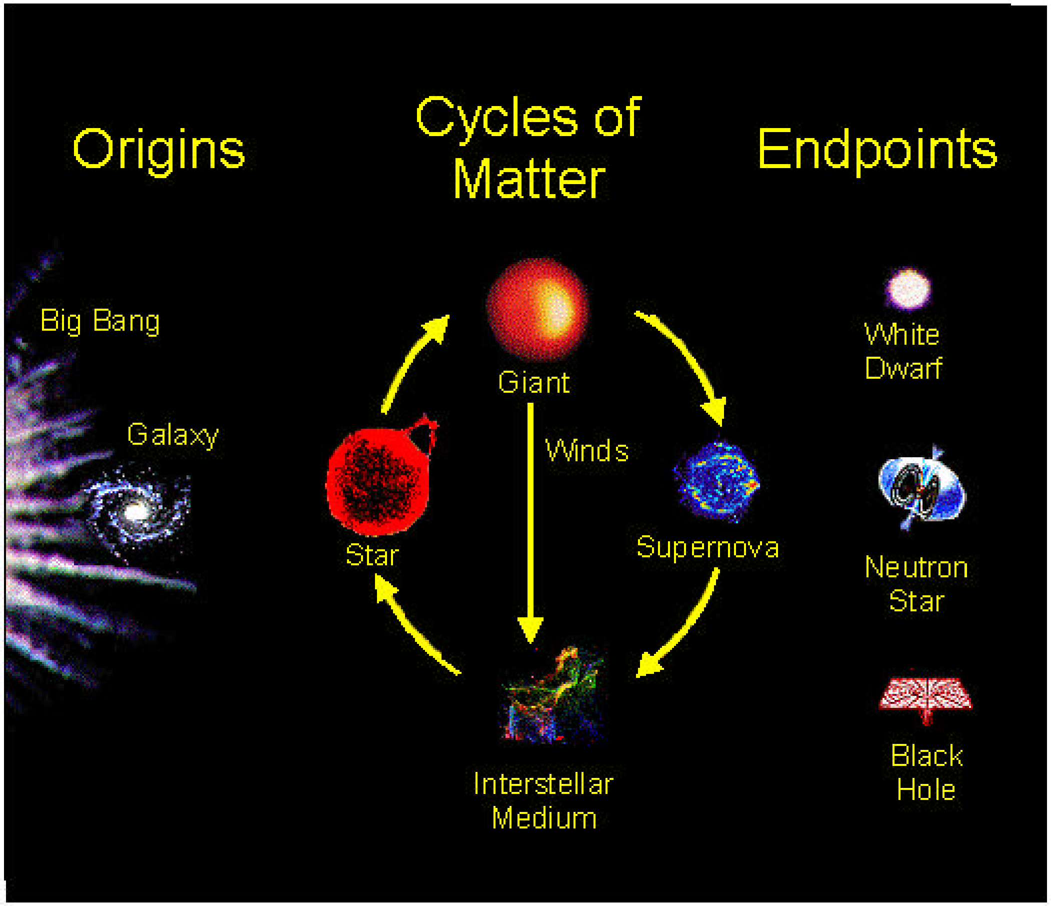
In Summer 1997, entered pre-Phase A study as facility class mission

- Renamed The Constellation X-ray Mission Constellation-X in October 1997

Studying the Life Cycles of Matter with the Constellation X-ray Mission

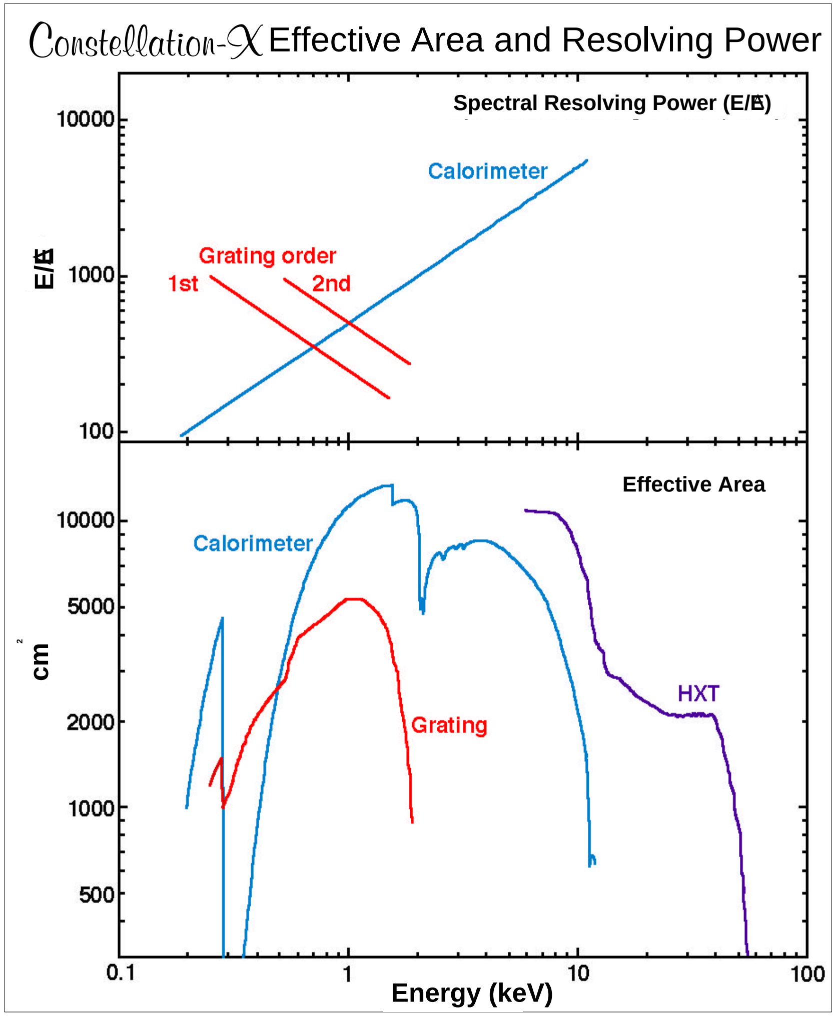
Obtain high quality X-ray spectra for all classes of X-ray sources over a wide range of luminosity and distance to determine:

- **the abundance of elements with atomic number between Carbon and Zinc (Z=6 to 30) using line to continuum ratios**
- **the ionization state, temperature, and density of the emission region using plasma diagnostics**
- **the underlying continuum process with a broad bandpass**
- **dynamics from line shifts and line broadening**



Constellation-X Science Payload

Two coaligned telescope systems cover the 0.25-40 keV band.



A spectroscopy X-ray telescope (SXT) from 0.25 to 10.0 keV

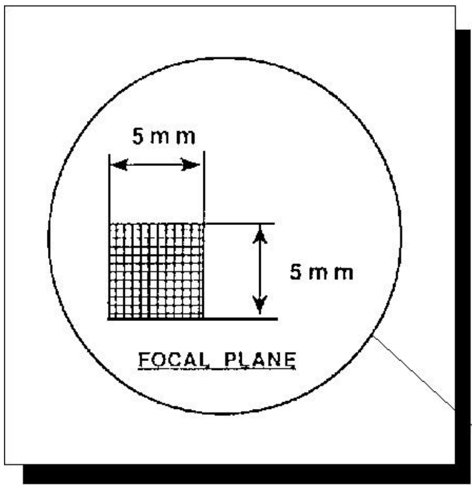
- an array of microcalorimeters with 2 eV resolution.
- a reflection grating/CCD to maintain resolution > 300 below 1 keV

A hard X-ray telescope (HXT) from 10 to 40 keV

- grazing incidence optics
- an energy resolution ~1 keV, sufficient to measure the continuum

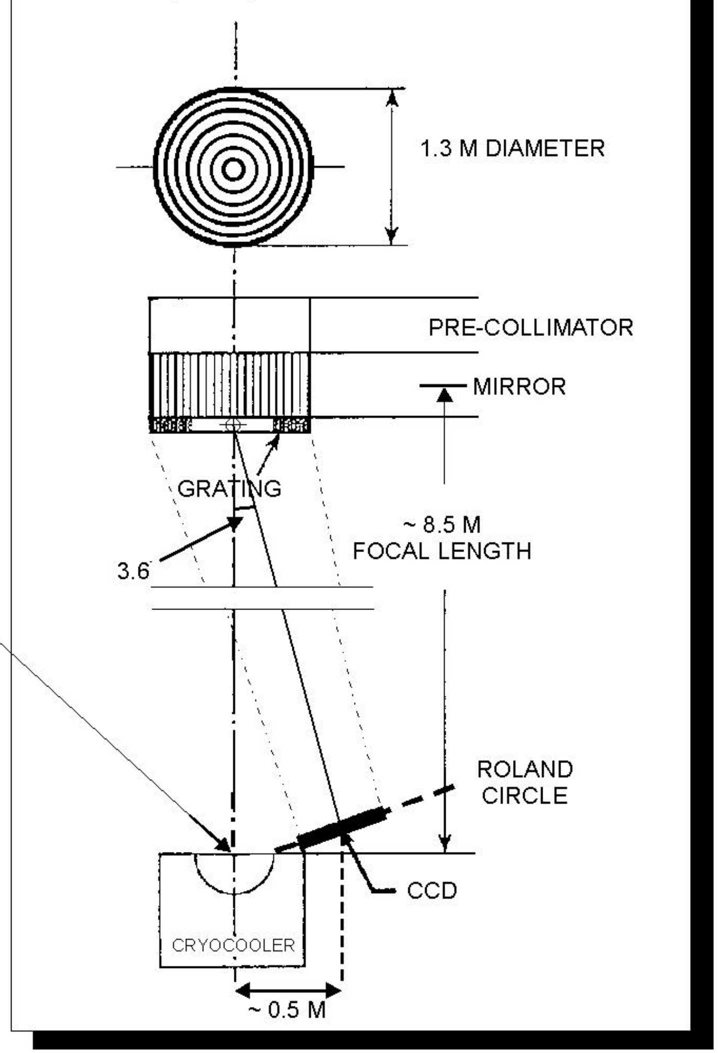
Constellation-X Instrumentation

Calorimeter Array



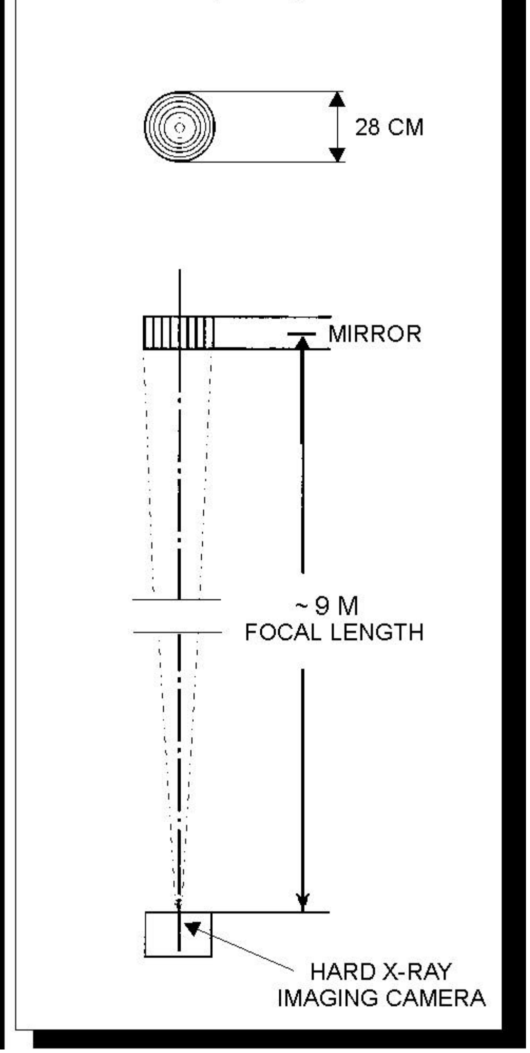
Spectroscopy X-ray Telescope

One unit per spacecraft

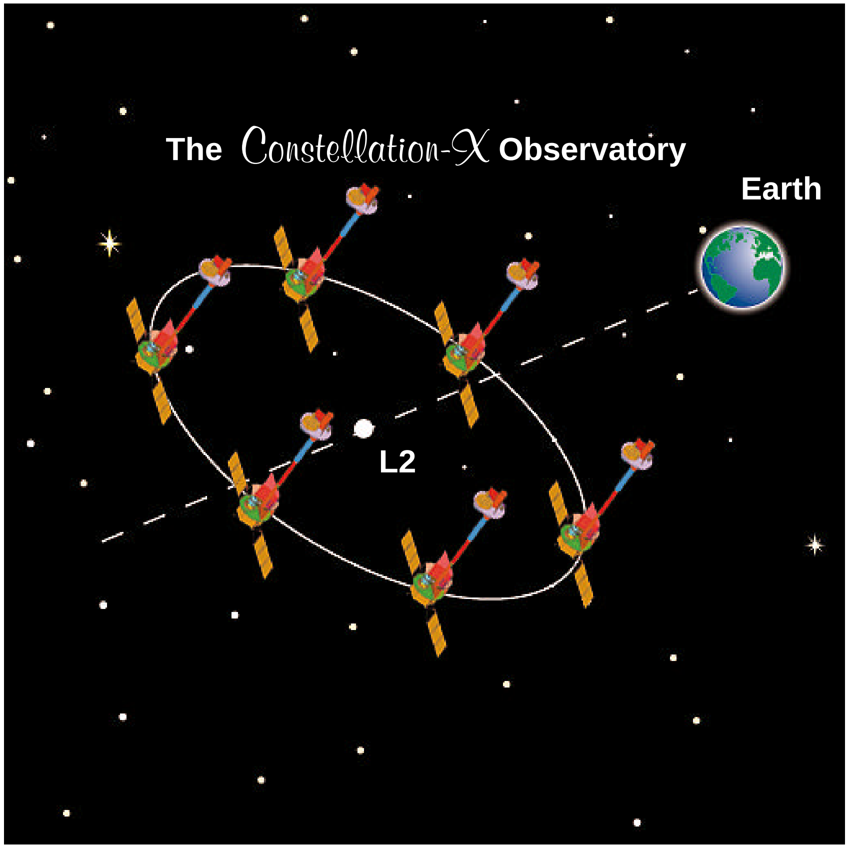


Hard X-ray Telescope

Three units per spacecraft



A Multi-Satellite Constellation-X Approach to Large Collecting Area



To achieve 15,000 cm^2 effective area on a single satellite requires a Titan-class launch.

An alternative low-risk approach to achieve large X-ray collecting area is to utilize a constellation of six identical low-cost Delta-class satellites.

Launch intervals of three months.

Facilitate simultaneous viewing and high efficiency by using libration point orbit.

The telescopes require a focal length of 8.5 m and use an extendible optical bench to allow a Delta-class launch.

Each spacecraft design lifetime is three years, with consumables targeted for a five-year mission.

Constellation-X Requirements Flow Down

Science Goals

Elemental Abundances and Enrichment throughout the Universe

Parameters of Supermassive Black Holes

Plasma Diagnostics from Stars to Clusters

Measurement Capabilities

Minimum effective area: 15,000 cm^2 at 1 keV
6,000 cm^2 at 6.4 keV
1,500 cm^2 at 40 keV

Telescope angular resolution: 15" HPD from 0.25 to 10 keV
1' HPD above 10 keV

Minimum spectral resolving power ($E/\Delta E$): 300 from 0.25 to 6.0 keV
3000 at 6 keV
10 at 40 keV

Band Pass: 0.25 to 40 keV

Key Technologies

High Throughput Optics

- *Lightweight ó 250 kg*
- *Replicated shells and segments*

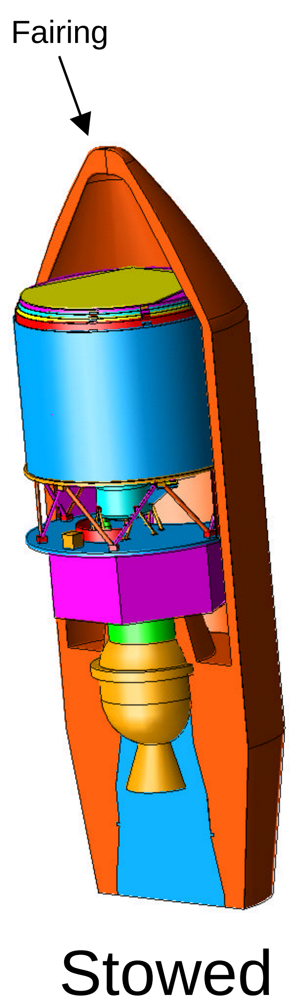
High Spectral Resolution

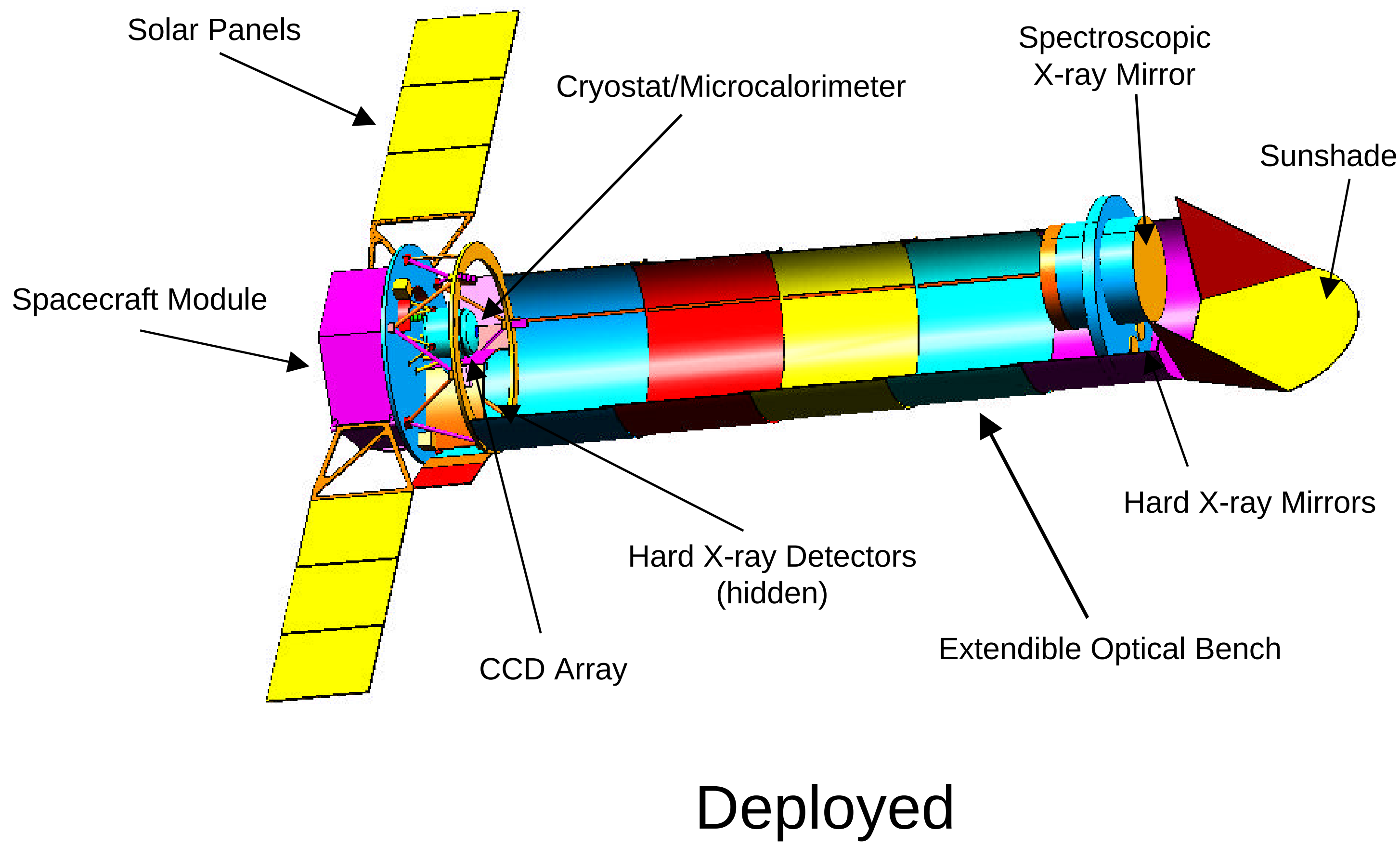
- *2 eV microcalorimeter arrays*
- *Coolers*
- *Lightweight gratings*
- *CCD arrays extending to 0.25 keV*

Broad Bandpass

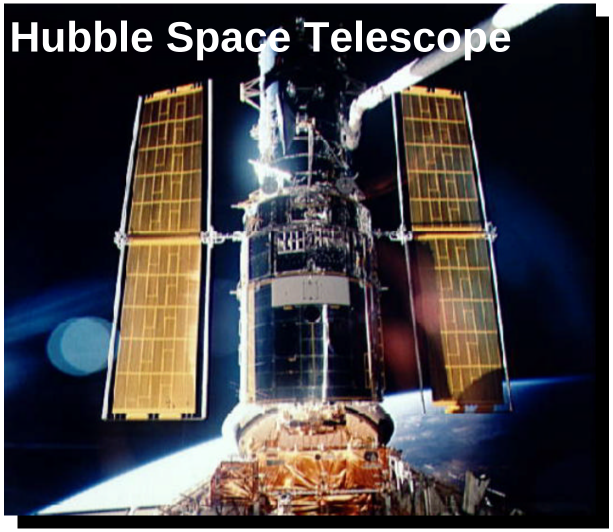
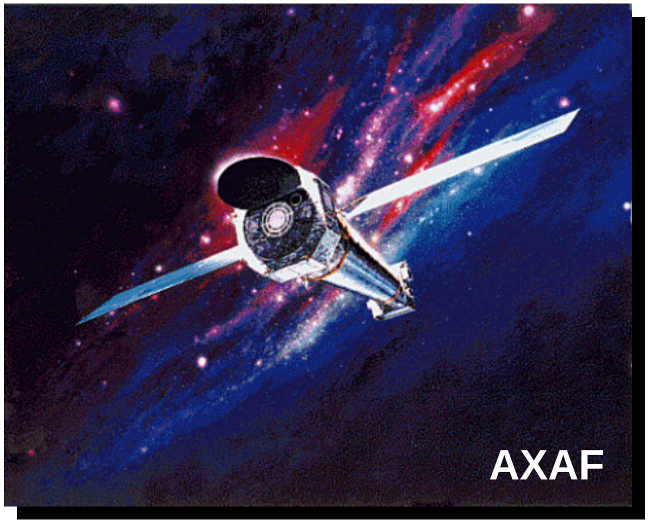
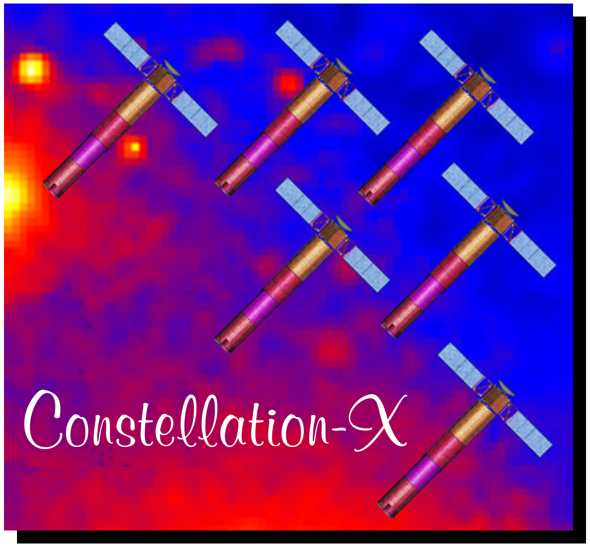
- *Multilayer optics*
- *CdZnTe detectors*

Constellation-X Reference Design



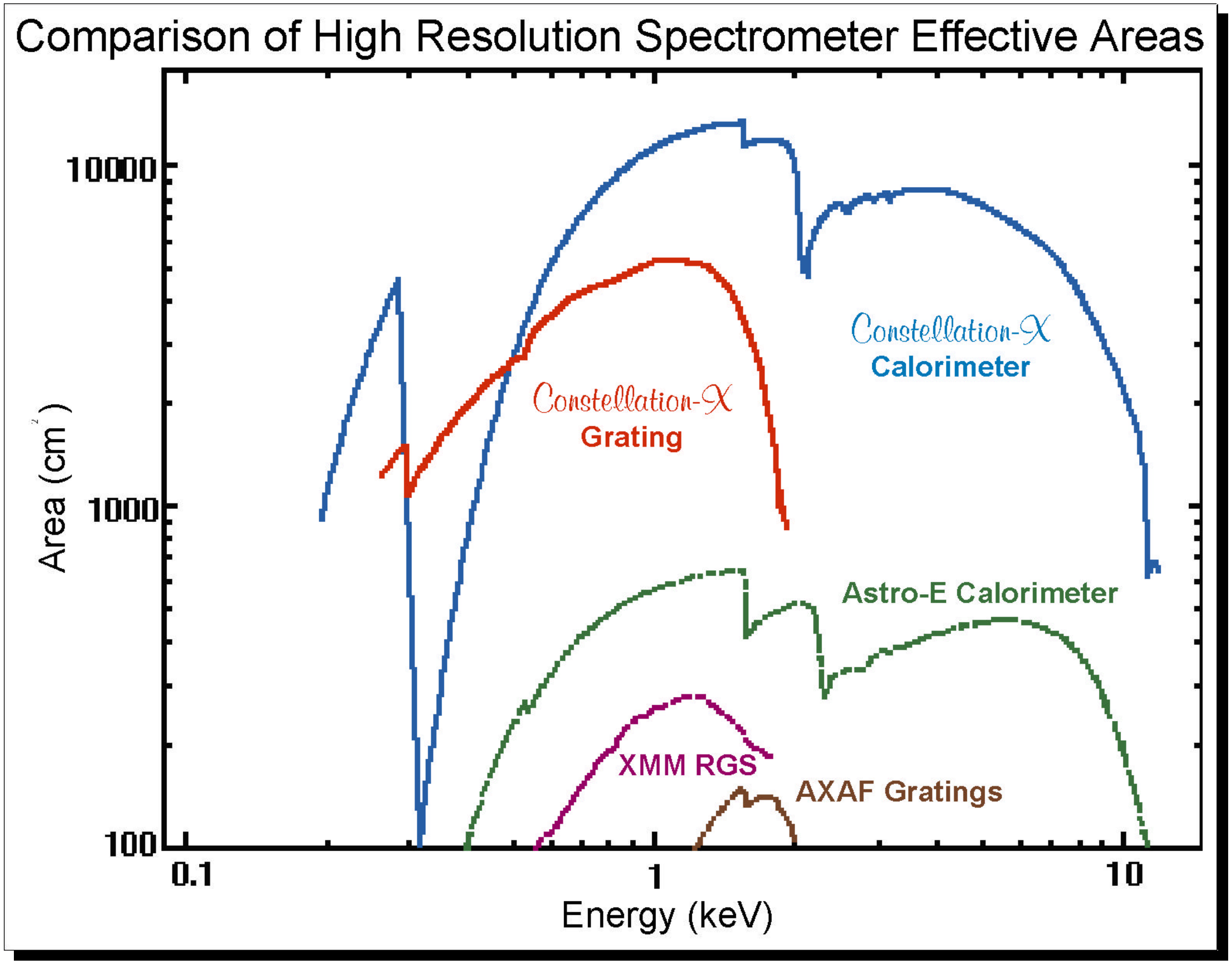


X-ray Equivalent of the Keck Telescope

Imaging		Spectroscopy	
 	0.1 arc sec 40,000 cm^2	 	1 arc sec 780,000 cm^2
 	0.6 arc sec 1,000 cm^2 (100 cm^2)*	 	15 arc sec 30,000 cm^2 (15,000 cm^2)*

* effective area at the spectrometer

Constellation-X Advanced Capabilities
I. High Throughput



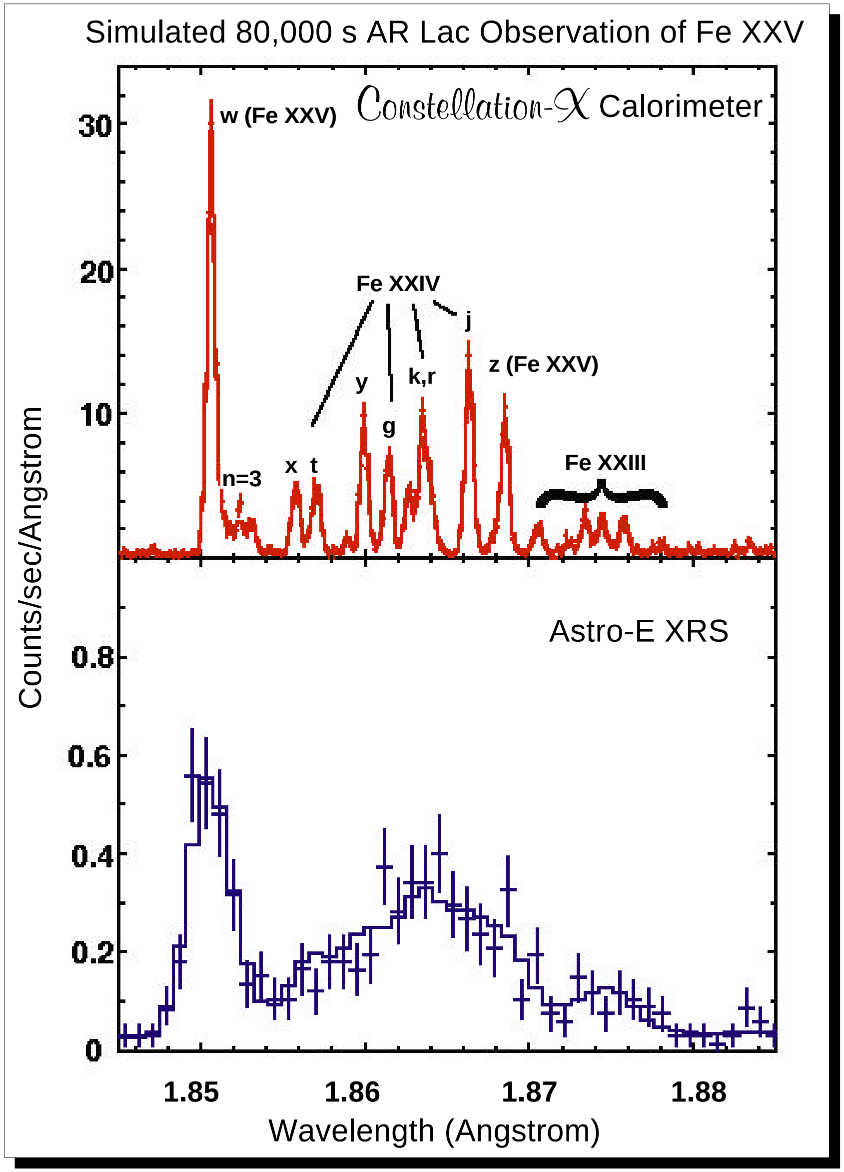
A 20-100 fold gain in effective area for high resolution X-ray spectroscopy

High throughput optics plus high quantum efficiency calorimeters

Lightweight reflection gratings maintain resolution and coverage at low energies

(< 1 keV)

Constellation-X Advanced Capabilities
II. High Spectral Resolution



The Next Generation Microcalorimeter Array

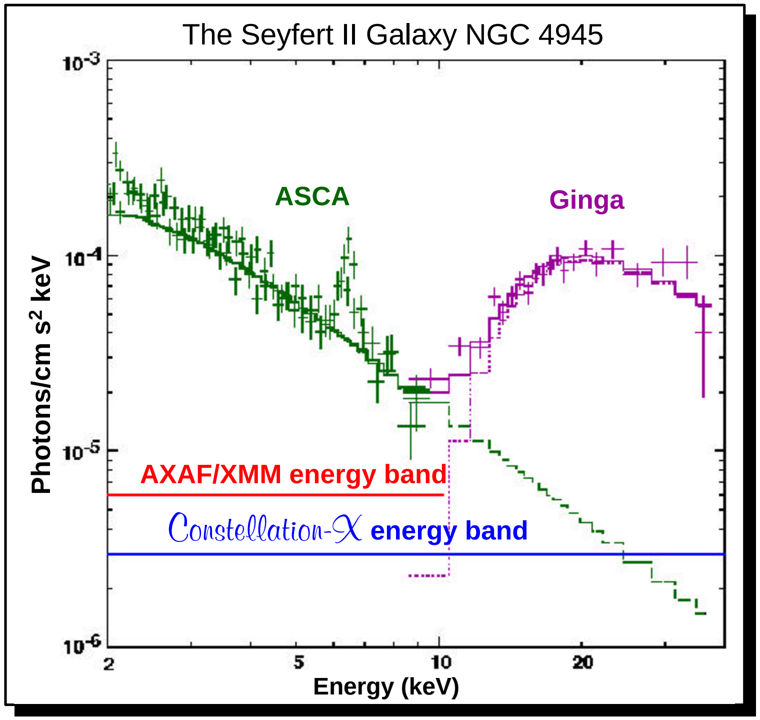
High quantum efficiency with the capability to map extended sources

- A factor of 5 improvement (to 2 eV) in spectral resolution
- Successor to the calorimeter to be flown on Astro-E (2000-2002)
- At Iron K, 2 eV resolution gives a velocity diagnostic of 10 km/s

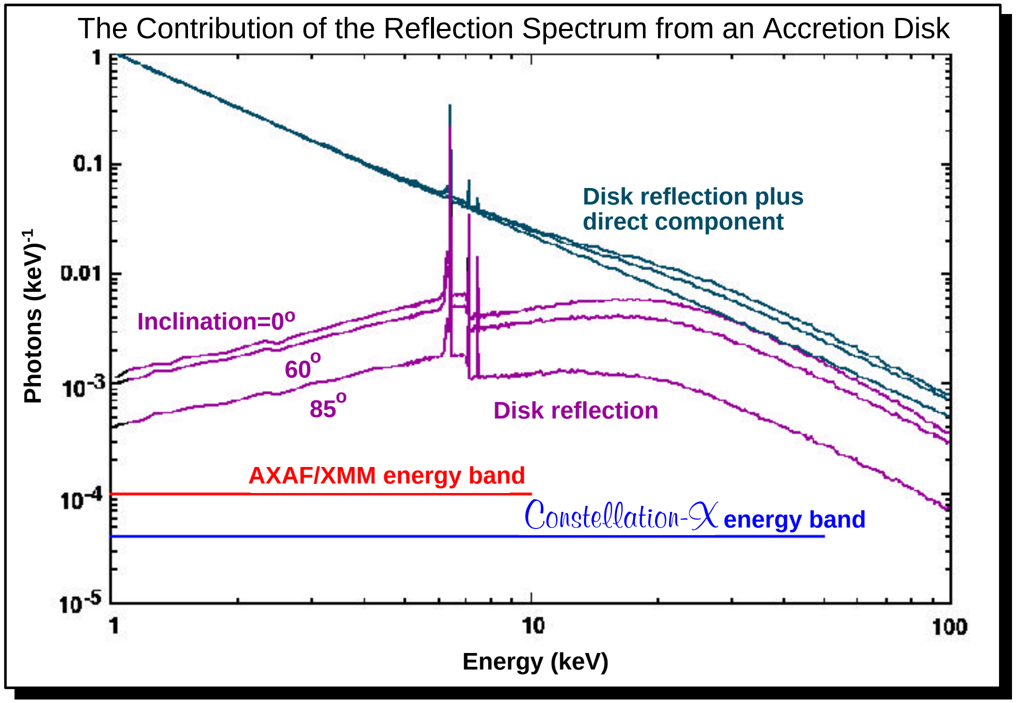
Hard X-ray Capability

The hard X-ray band is crucial to determine the underlying continuum

Planned missions (AXAF, AMM, Spectrum XG, and Astro-E) have limited or no sensitivity above 10 keV



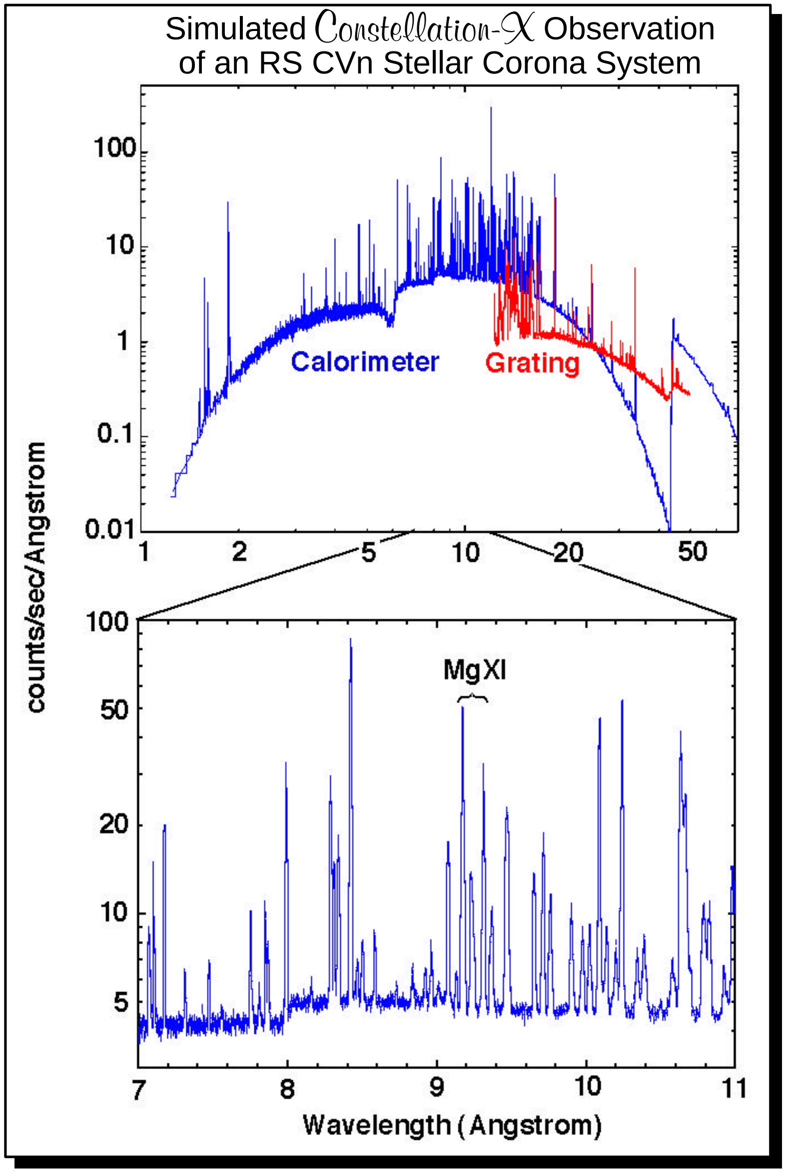
AGN viewed edge-on through the molecular torus



AGN viewed face-on

- **No previous instrument has employed focusing in the Hard X-ray band**
- **Multilayer coatings and hard X-ray pixelated detectors to increase high energy response**
- **Dramatic sensitivity improvements will be achieved**

Abundance Determinations with the Constellation X-ray Mission



The Constellation-X energy band contains the K-line transitions of 25 elements allowing simultaneous direct abundance determinations using line-to-continuum ratios

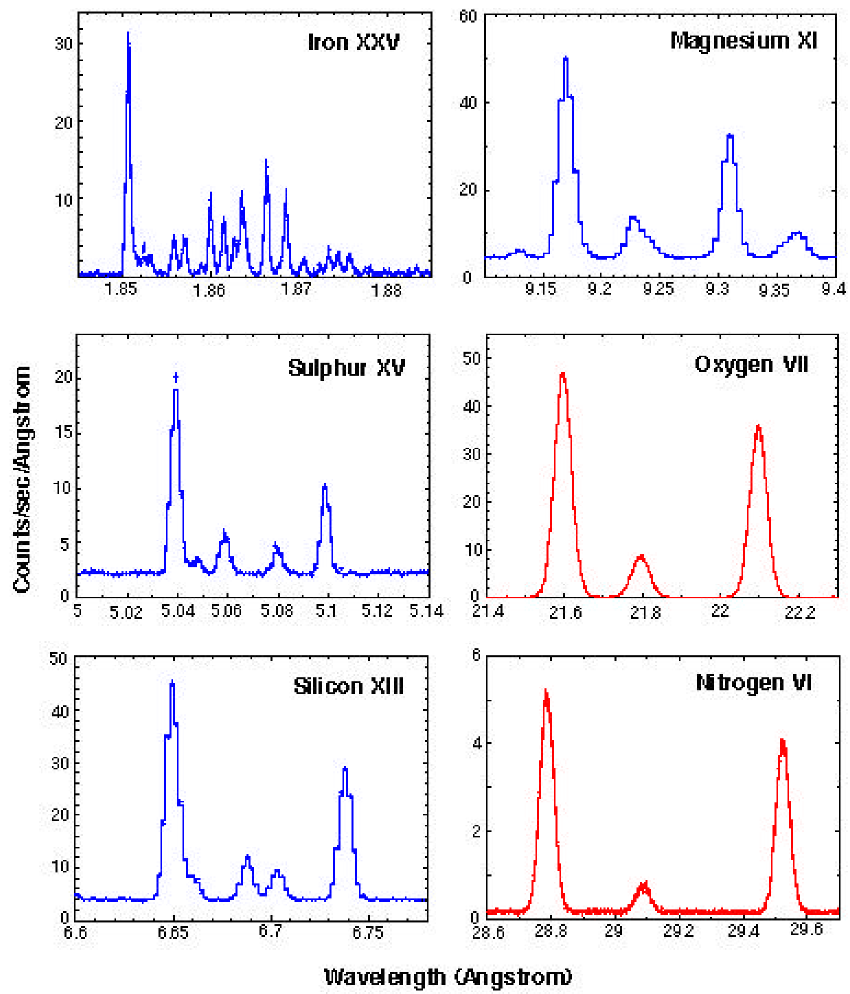
The sensitivity of Constellation-X will allow abundance measurements in:

- the intracluster medium in distant clusters,
- the halos of elliptical galaxies,
- starburst galaxies,
- stellar coronae,
- young and pre-main sequence stars,
- X-ray irradiated accretion flows, and
- supernova remnants and the interstellar medium.

Temperature, Density, and Velocity Diagnostics

The spectral resolution of the Constellation X-ray Mission is tuned to study the He-like density sensitive transitions of Carbon through Zinc

A Selection of He-like Transitions Observed by Constellation-X



Direct determination of

- densities from 10^8 to 10^{14} cm^{-3}
- temperature from 1-100 million degrees.

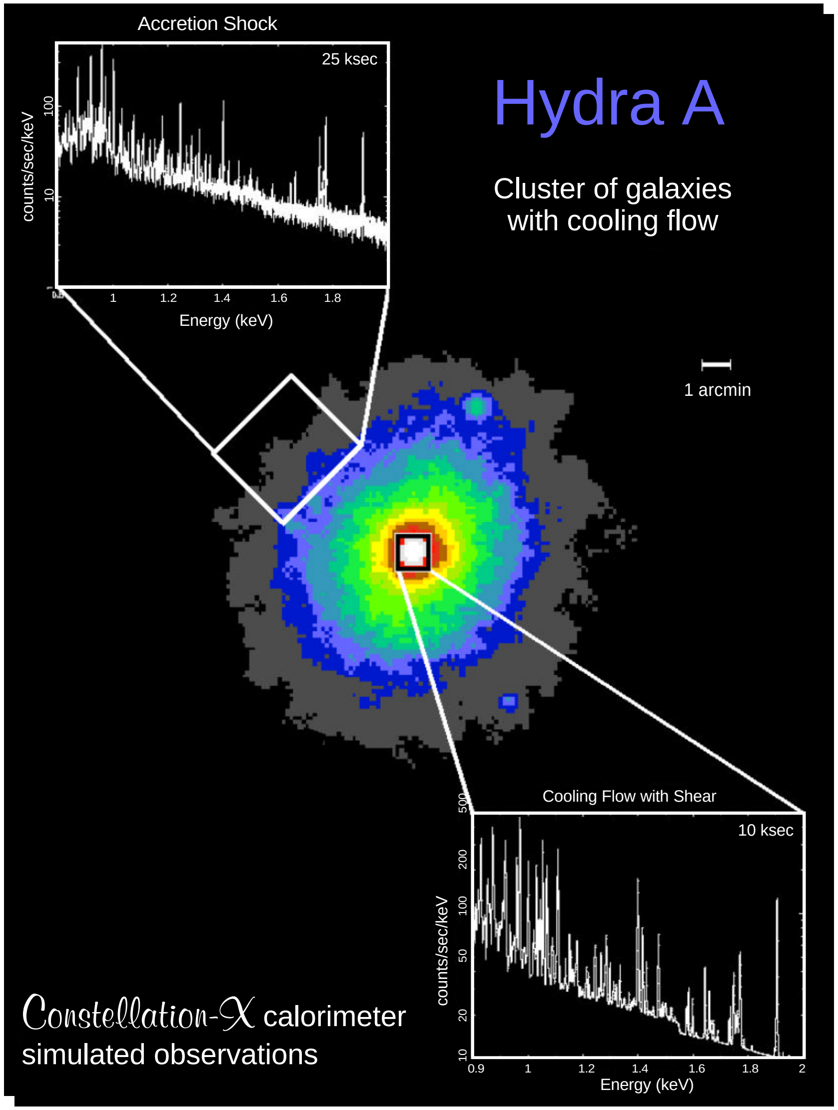
Velocity diagnostics at Fe K line:

- line width gives a bulk velocity of 100 km/s
- line energy gives an absolute velocity determination to 10 km/s

Simultaneous determination of the continuum parameters

Observations of Clusters of Galaxies

Baryon content of Universe is dominated by hot X-ray emitting plasma



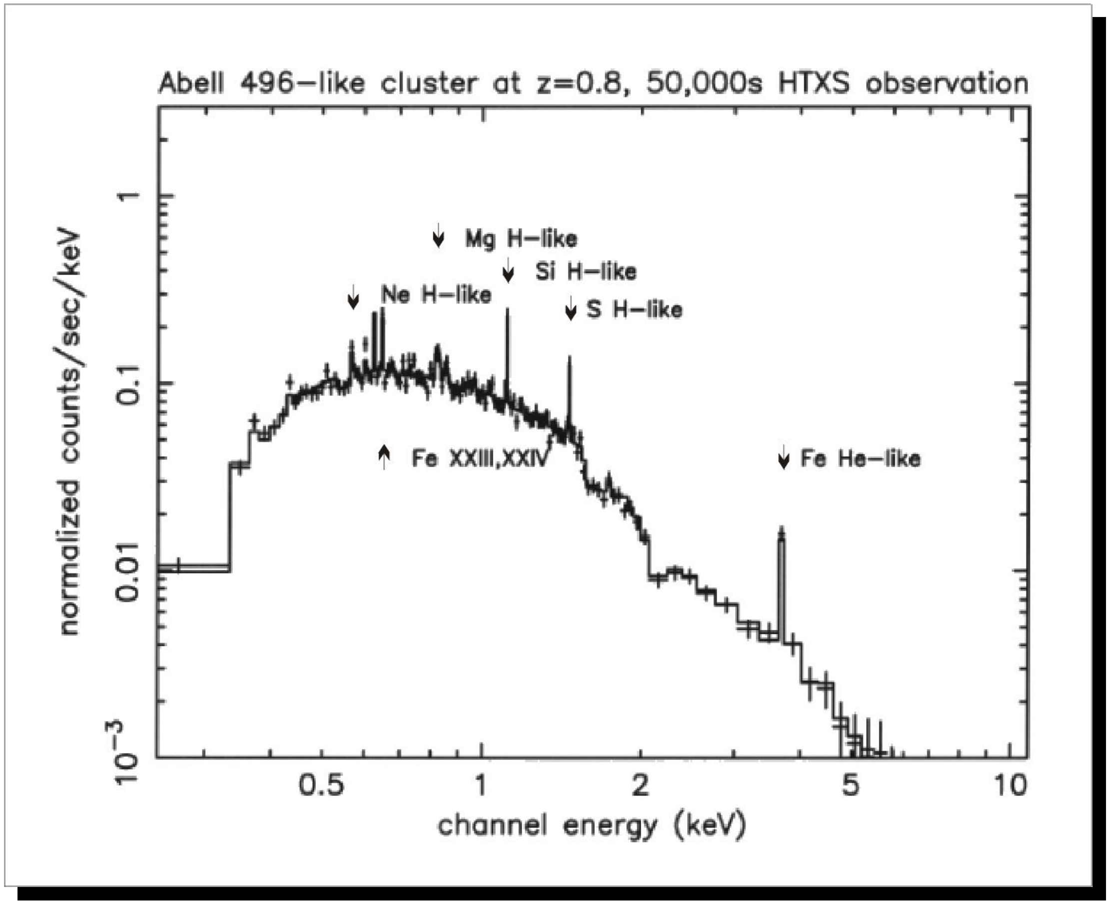
Clusters of galaxies are the largest and most massive objects known

Constellation-X observations of clusters essential for understanding structure, evolution, and mass content of the Universe

- Observe epoch of cluster formation and determine changes in luminosity, shape, and size vs redshift
- Measure abundances of elements from carbon to zinc, globally mapping generation and dissemination of seeds for earth-like planets and life itself
- Map velocity profiles, probing dynamics and measuring distributions of luminous and dark matter

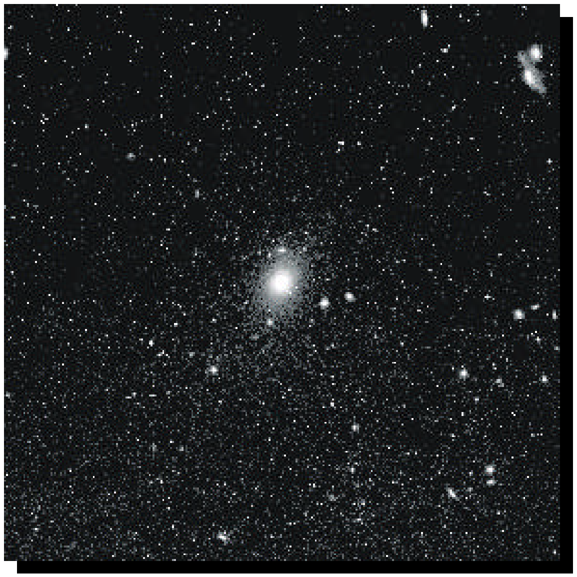
Constellation-X Observations of High z Clusters

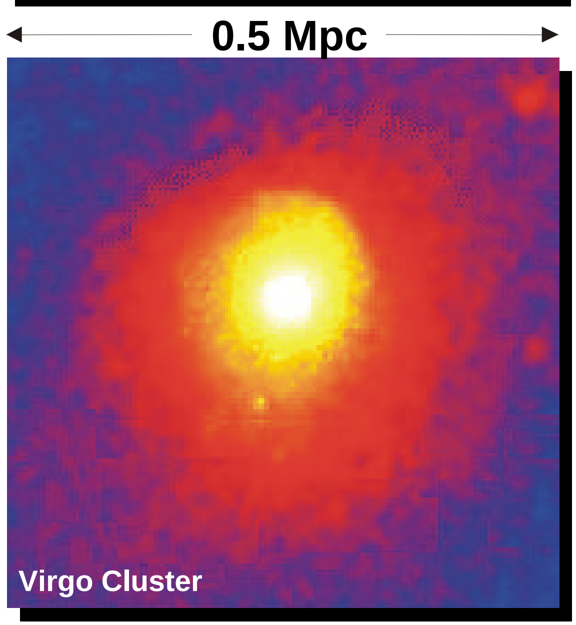
A simulated 50,000 s exposure of a cluster at z=0.8:



- Luminosity of 3.5 x 10^{44} ergs/s
- Temperature of 4 keV
- Type II abundance distribution
- Abundances are determined to 10% accuracy for Si, S, and Fe and 20% for Ne and Mg

Constellation-X Observations of Galaxies

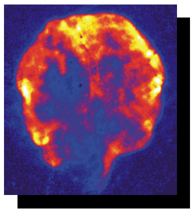




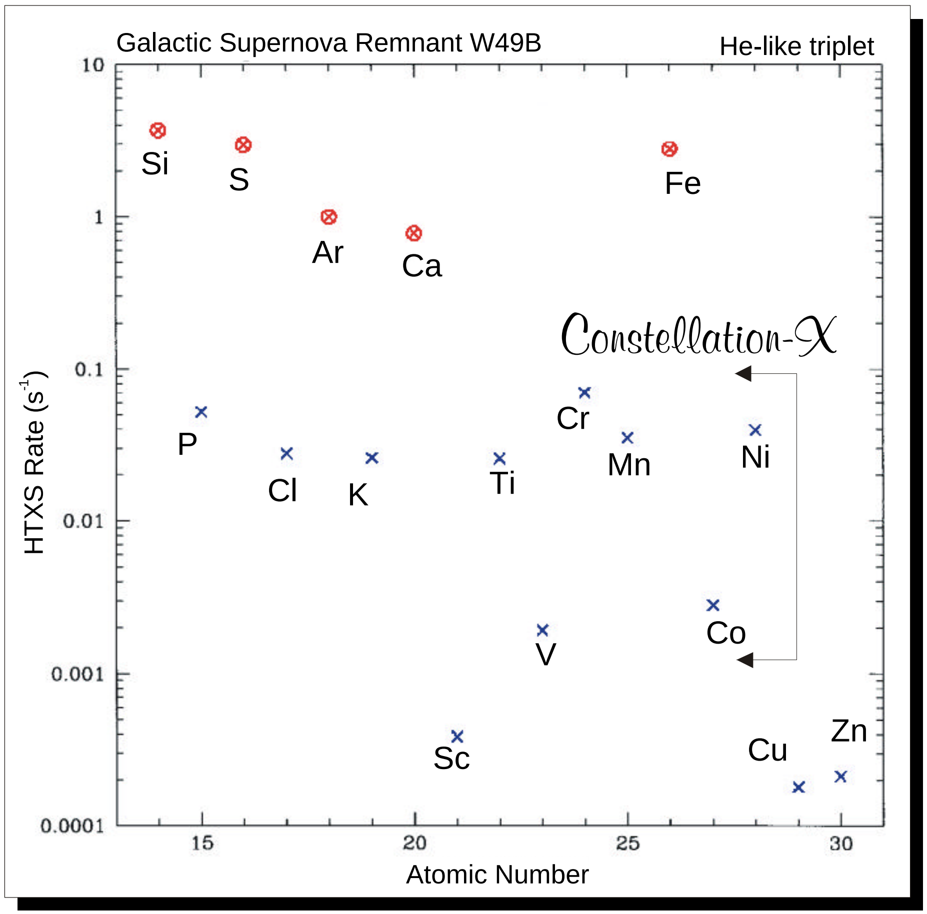
- Make in situ measurements of the abundance and density of the hot halos of elliptical galaxies out to high redshift.
- Study outflows associated with starburst galaxies.
- Unravel the complex multiphase nature of the hot ISM in nearby spirals and irregular galaxies.
- Study X-ray binary populations in galaxies located as far away as the Virgo Cluster.

Constellation-X

Constellation-X Measurements of Chemical Enrichment

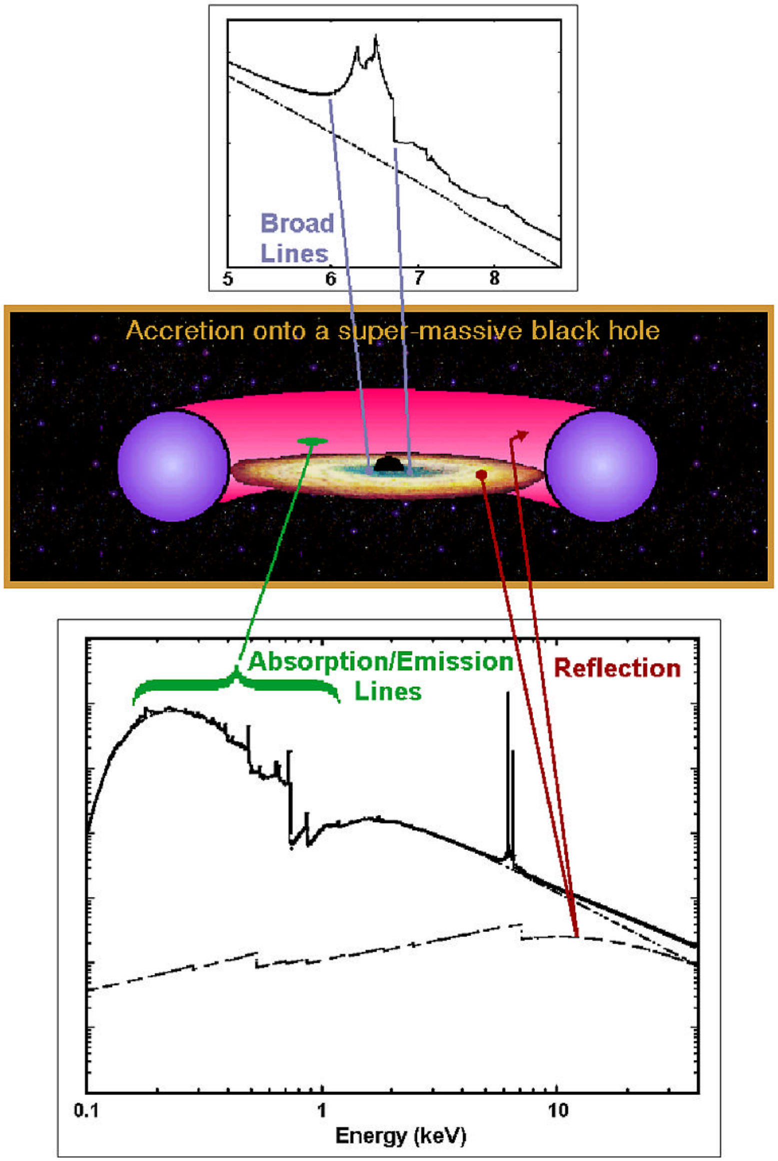


Stellar evolution in galaxies drives the chemical evolution of the Universe.



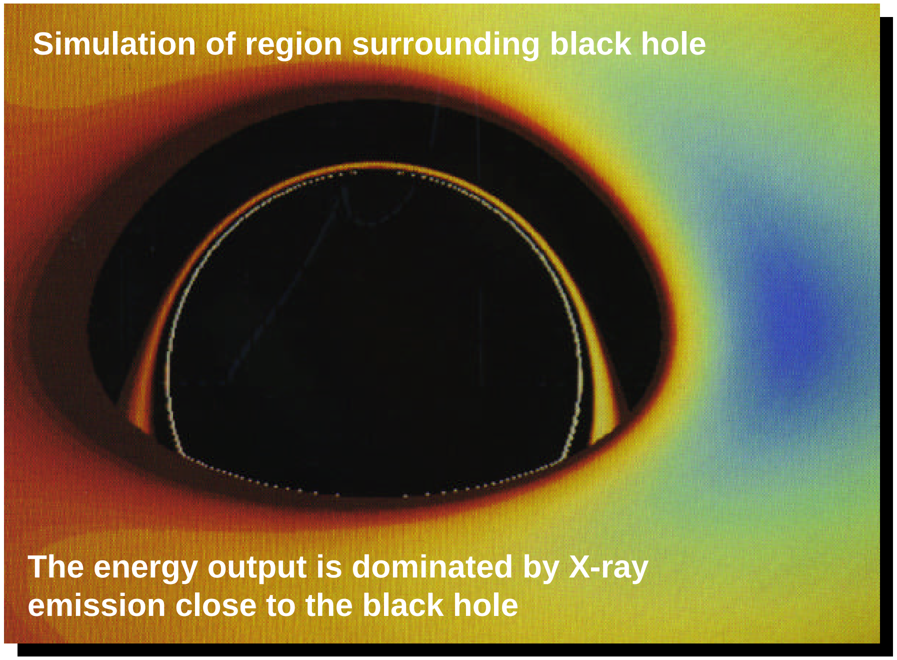
- Type supernova remnants using high resolution spectra of remnants in external galaxies located out to the distance of the Virgo Cluster.
- Determine the abundances and velocity distribution of even- and odd-Z elements from Carbon to Zinc in extended supernova remnants.
- Map the abundance of the hot ISM in nearby galaxies.
- Use non-thermal signatures to identify sites of cosmic ray acceleration in young supernova remnants.

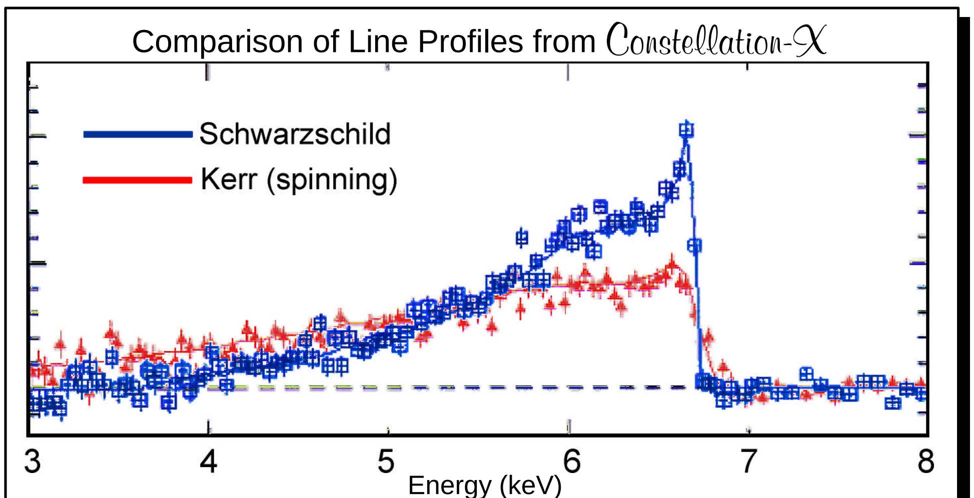
Observations of Supermassive Black Holes with the Constellation X-ray Mission



- Obtain the first detailed X-ray spectra of AGN out to redshift 5
- Study the faint AGN populations
- Resolve narrow X-ray emission line components in the spectra of AGN
- Test general relativity in the strong gravity limit.
- Determine the rotation rate and mass of black holes
- Determine the geometry of the accretion flow

Constellation-X Will Determine the Nature of Supermassive Black Holes

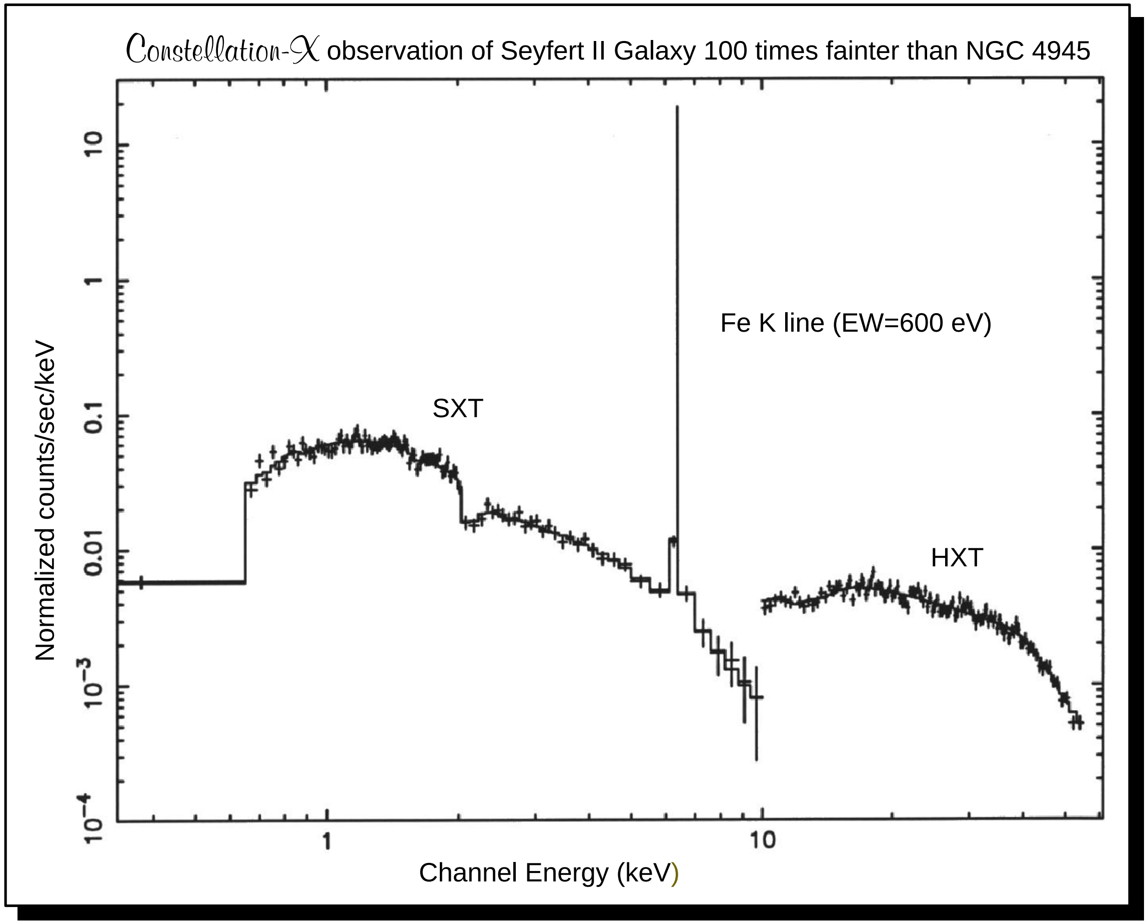




- Active galactic nuclei and quasars powered by accretion of matter onto supermassive black holes
- X-rays produced near event horizon and probe 100,000 times closer to black hole than HST
- Relativistically broadened iron lines probe inner sanctum near black holes, testing GR in strong gravity limit
- Constellation-X will determine black hole mass and spin using iron K line
  - Spin from line profiles
  - Mass from time-linked intensity changes for line and continuum

Constellation-X Observation of Seyfert II Galaxy

Seyfert IIs may be the dominant AGN population



100 times fainter than NGC 4945

- $\sim 10^{-13}$ erg cm^{-2} s^{-1}
- 10^5 s exposure

HXT observes central source

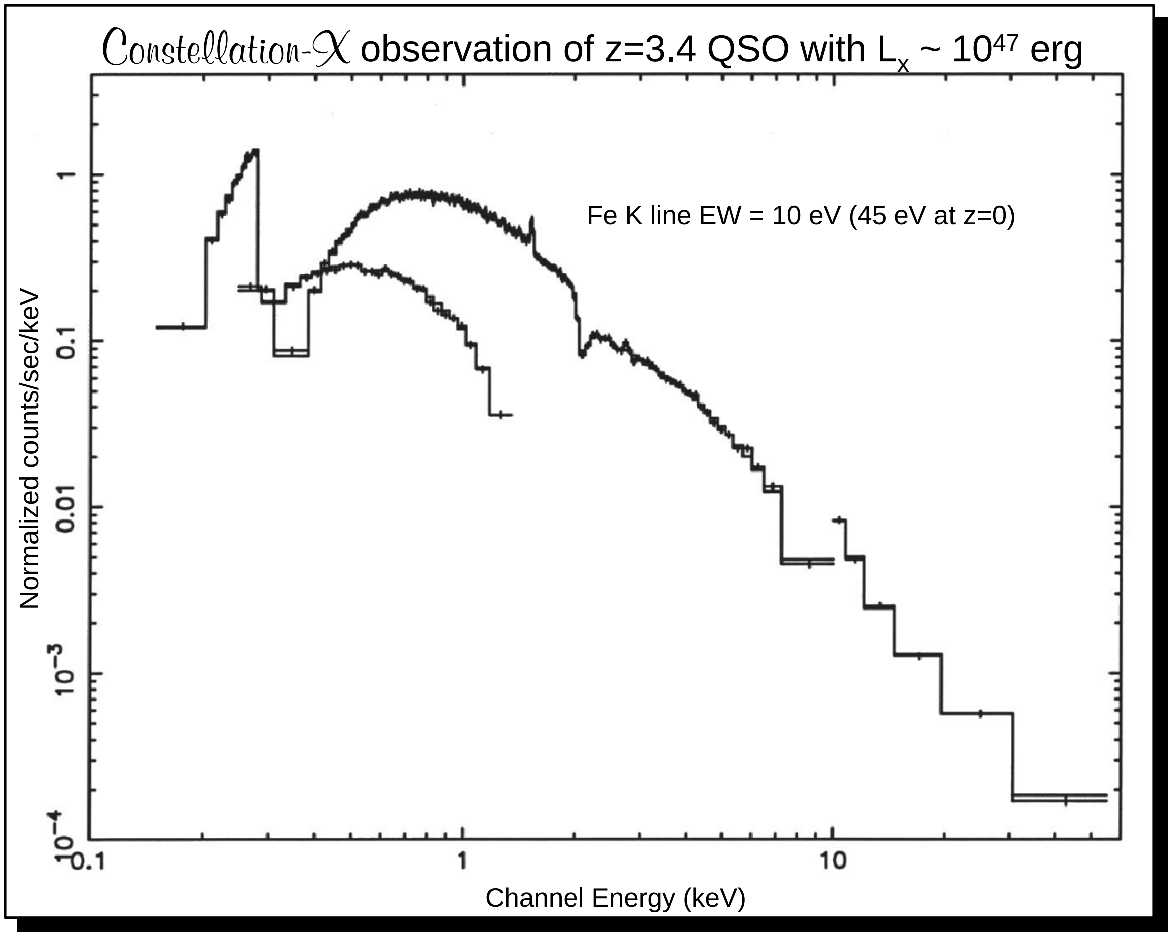
- highly absorbed by torus

SXT observes scattered emission

- fluorescent Iron K line

Constellation-X Observation of High Redshift QSO

Simulated 10^5 s Constellation-X Observation of z=3.4 QSO with $L_x \sim 10^{47}$ erg



Determine continuum

- rest frame 0.8-175 keV

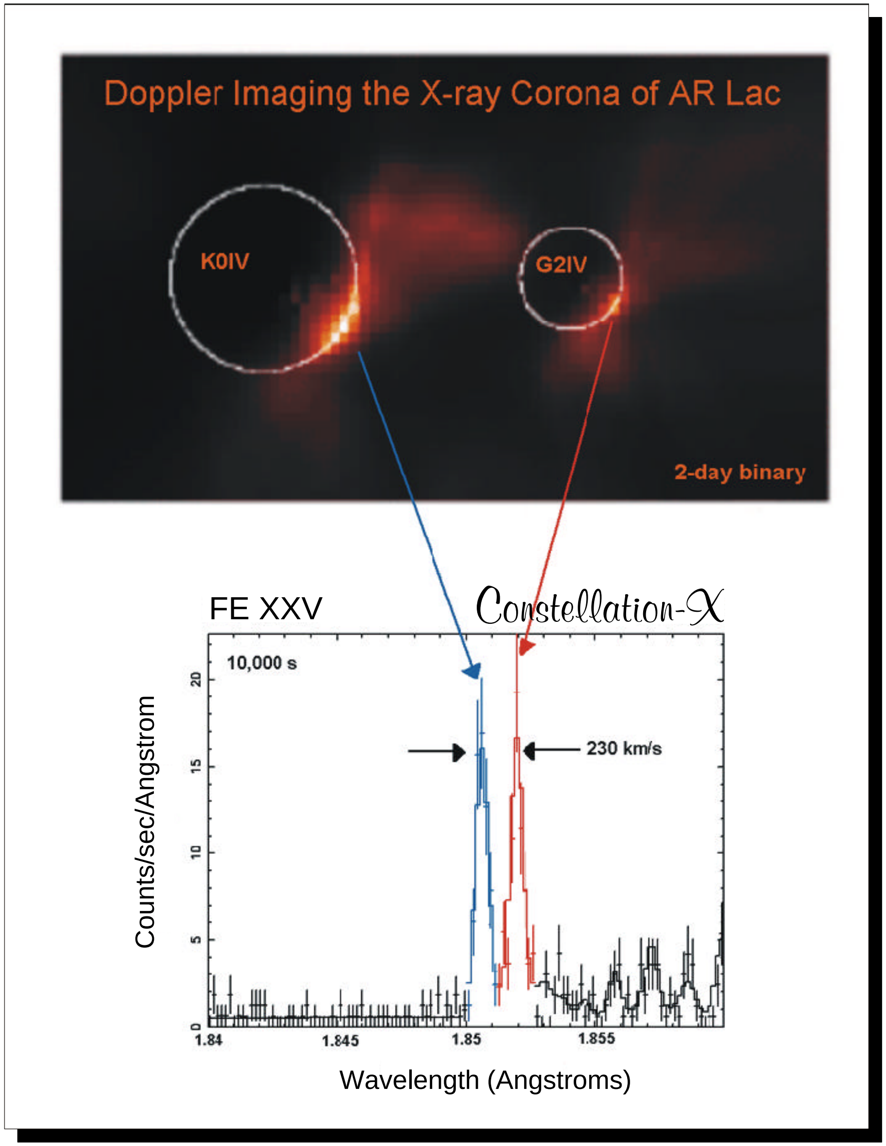
Search for line emission

- Fe abundance at high z
- broadening of line
- ionization state

Measure absorption edges

- probe gas along line of sight

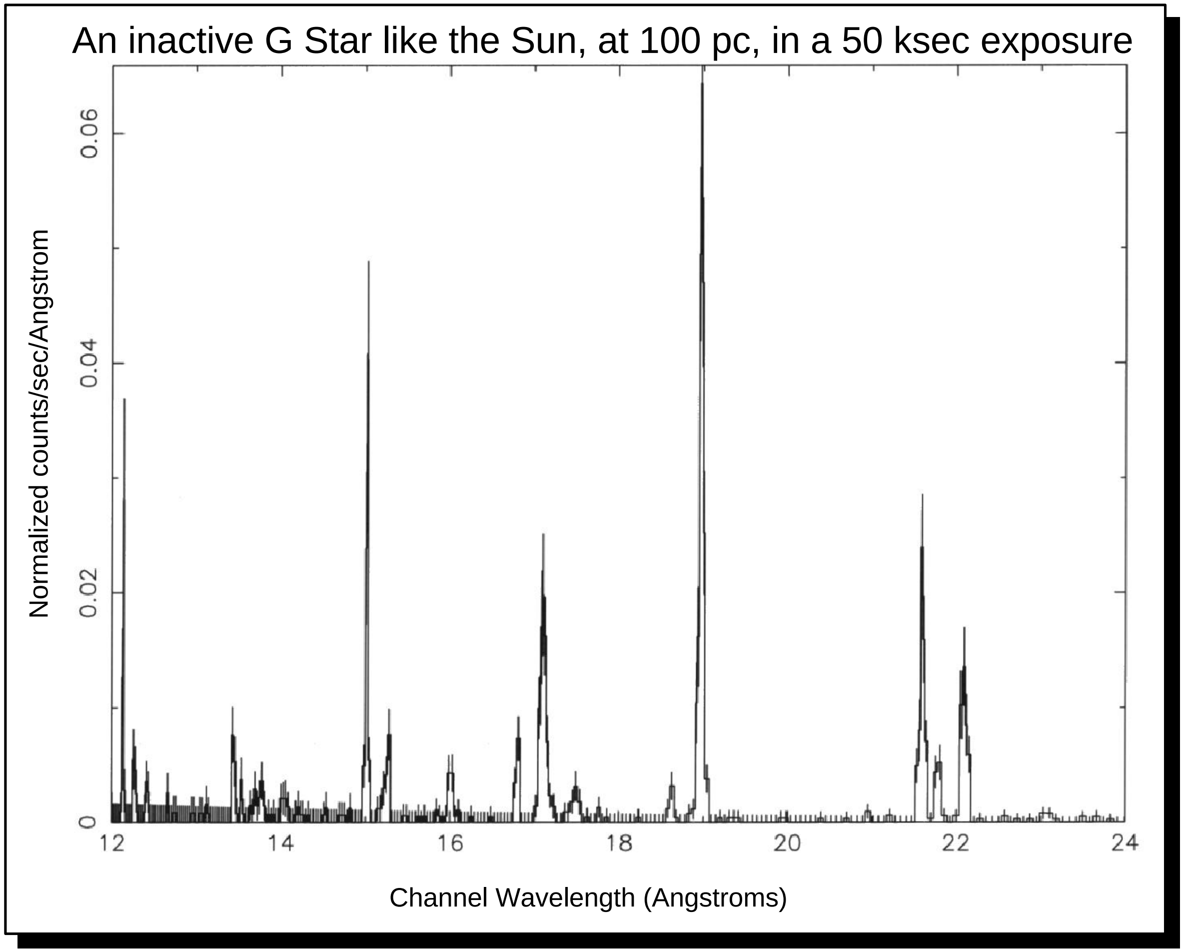
Constellation-X Observations of Stellar Coronae



- Plasma spectroscopy and Doppler imaging of coronal activity stars
- Study magnetic reconnection, mass motion, densities, and abundances in stellar flares
- Investigate the formation and evolution of magnetic dynamos in young and pre-main sequence stars in molecular clouds
- Obtain high resolution spectra of stellar coronae from a wide range of luminosity
- Obtain high quality spectra of active stars such as RS CVn and Algol systems out to ~30 kpc

Constellation-X Observations of Low Luminosity Stellar Coronae

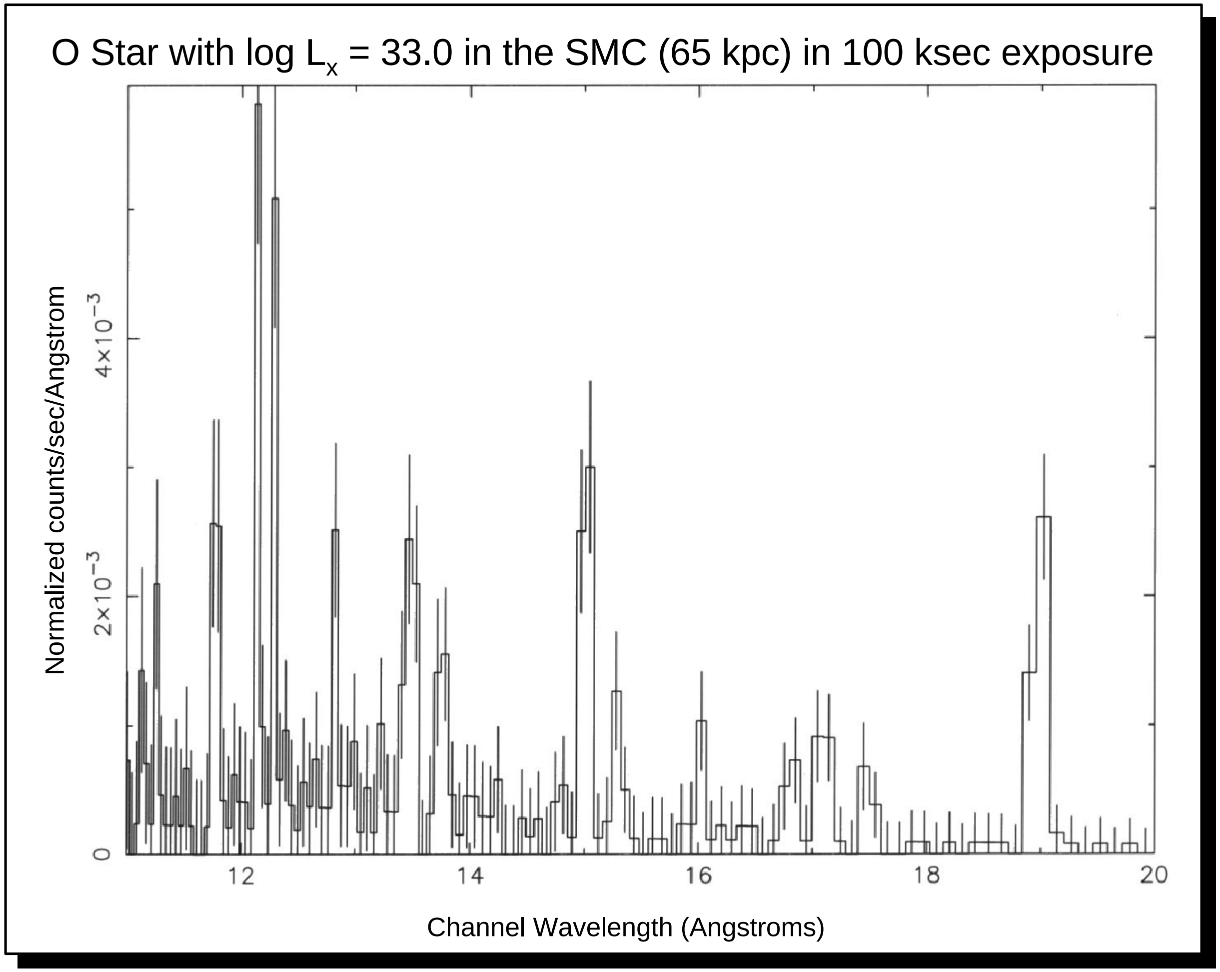
A simulated Constellation-X spectrum of a stellar corona from a star like the Sun (Lx ~ 10^{27} erg/s) at a distance of 100 pc



Derive detailed temperature, structure, and elemental abundances for all types of stars

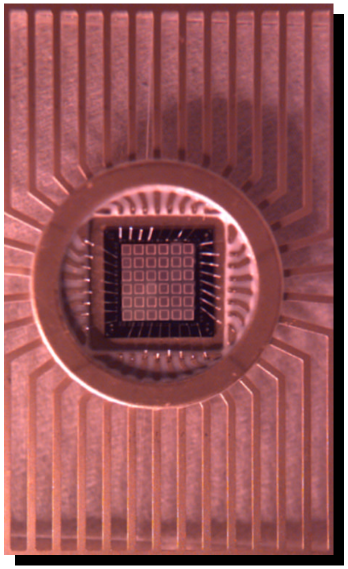
Constellation-X Observations of the Coronae of Early Stars

Simulated spectra of an O star with Lx ~ 10^{33} ergs/s in the Small Magellanic Cloud

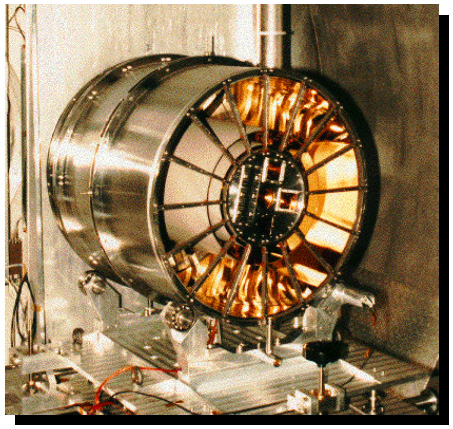


- Obtain high quality spectra for all hot stars with D < 30 kpc which do not have have excessive ISM absorption columns
- Wolf-Rayet stars with Lx ~10^{34} erg/s in the LMC/SMC and other nearby (< 300 kpc) dwarf galaxies in the Local Group
- Determine abundances, temperature, structure, and absorption in the stellar wind/ISM

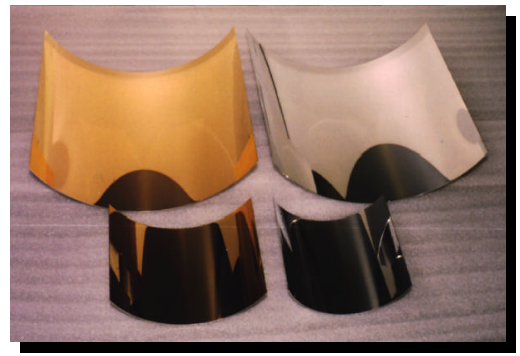
Constellation-X Technology Requirements



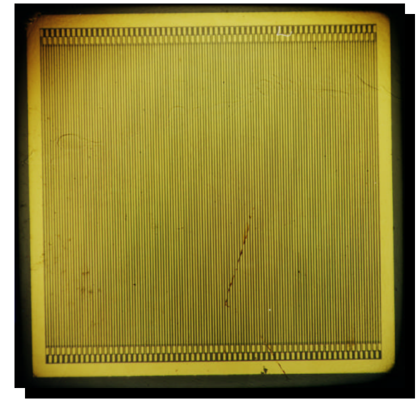
Microcalorimeters



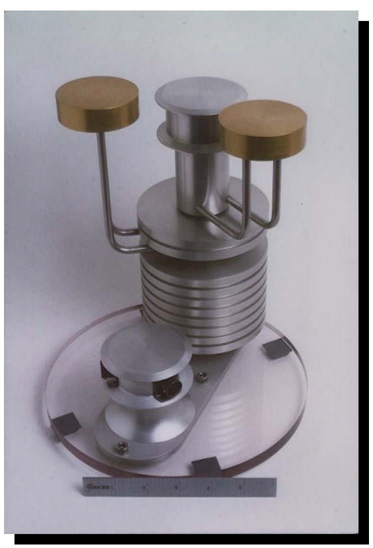
Lightweight
X-ray Optics



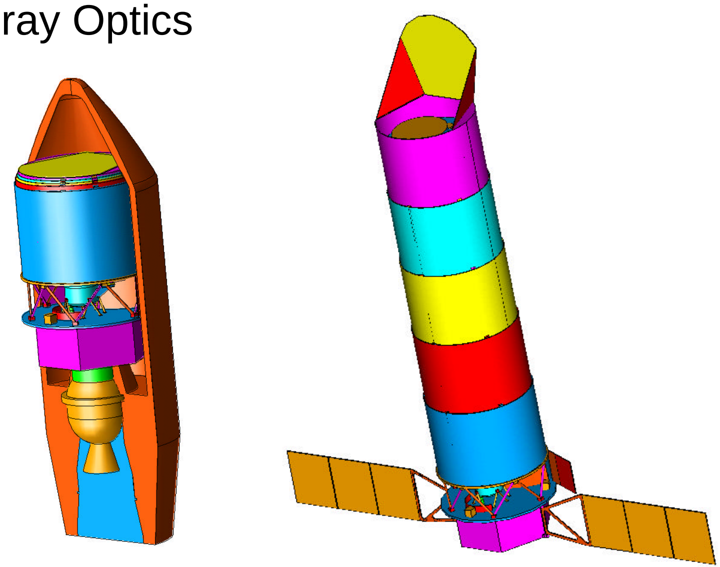
Multilayer Coatings



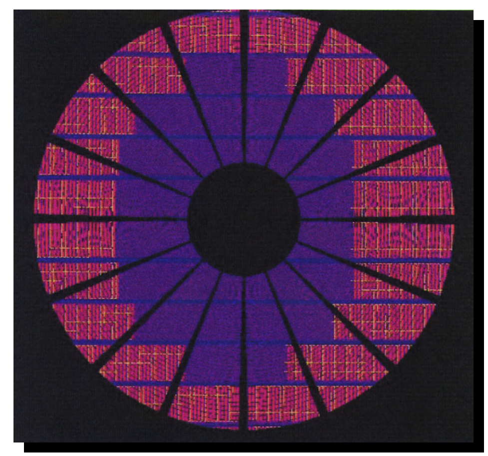
CdZnTe Arrays



Coolers

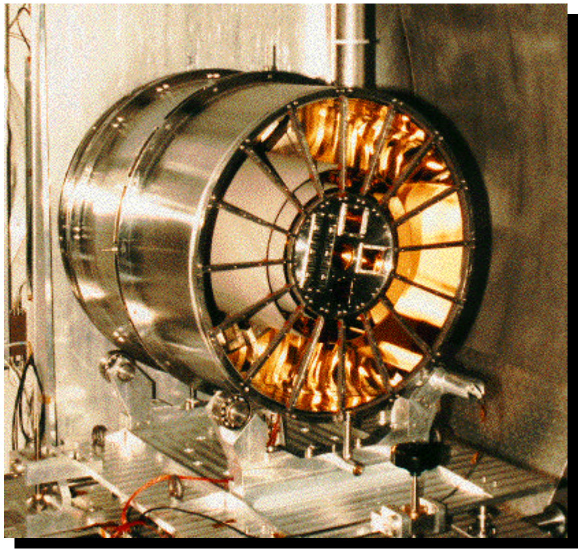


Deployable Structures



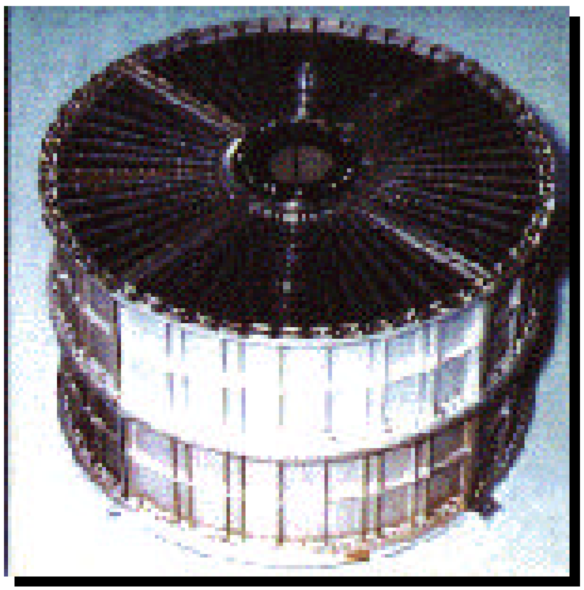
CCD/Grating

SXT X-ray Mirror Design Alternatives



Replicated Shells (e.g., XMM):

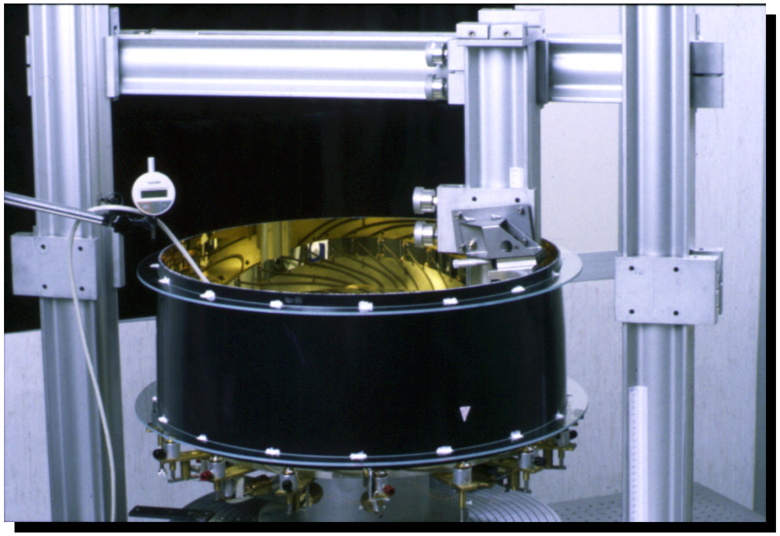
- meets 15" angular resolution
- requires factor of 10 weight reduction (2,500 kg --> 250 kg)
- investigate SiC, cyanate ester, and other lightweight carriers
- thin-walled rib-reinforced Ni shells

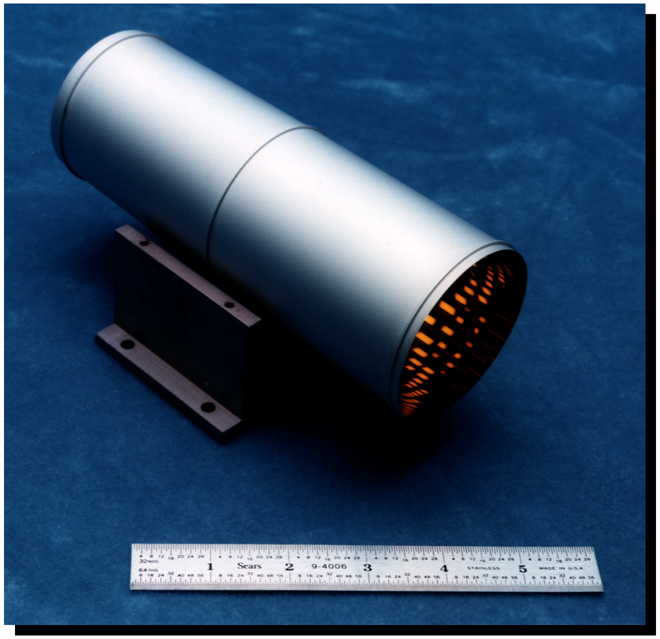


Segmented Optics (e.g., Astro-E):

- 210 kg weight meets the requirement
- requires factor of 4 improved angular resolution
- improved mandrels and foil alignment techniques

Spectroscopy X-ray Telescope Progress on Replicated Shells





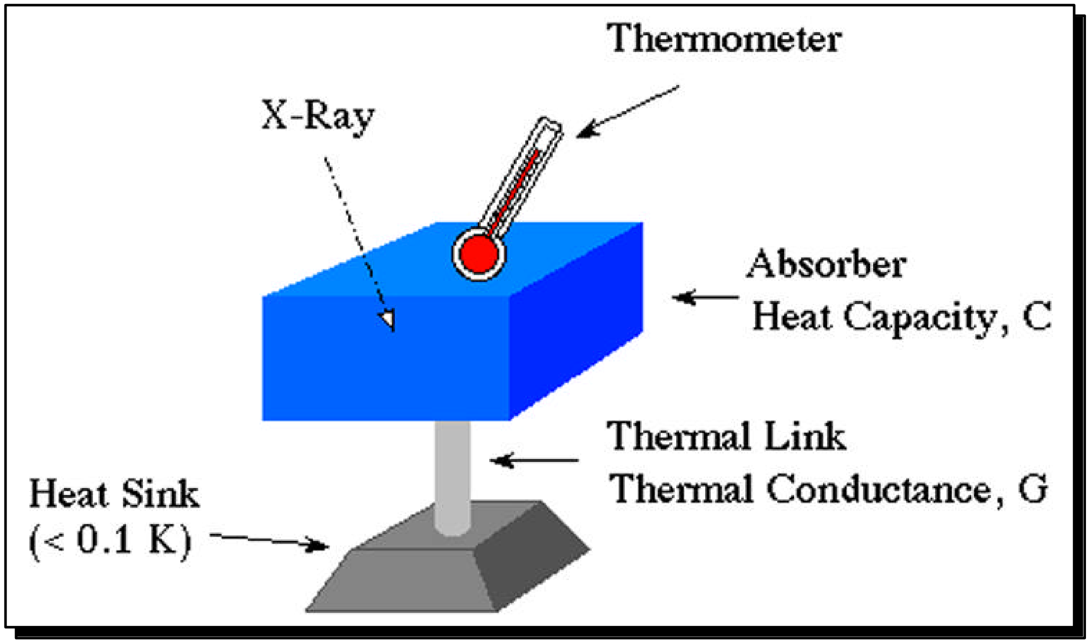
Alumina (Al_2O_3) carrier shells produced in Italy at OAB -- lower temperature process, simpler, lower cost than SiC

- Carrier with 600 mm diameter and 3.2 mm walls produced by plasma spray
- Optical surface replicated successfully -- X-ray test in 1997
- Lighter weight alumina carrier -- same diameter, 0.5 mm walls, three (3.3 mm) stiffening ribs
- Replicate this summer, then X-ray test

Progress on replicated shells at MSFC:

- Thin Ni shells with reinforcing ribs fabricated and ready for X-ray test
- Fabricated two 0.5 m diameter mandrels
- Modified equipment to handle 1.3 m diameter mandrels
- Awarded contracts for SiC and composite carriers

Requirements on the Constellation-X Microcalorimeter Array



A detector with 2 eV spectral resolution over the 0.3 - 12 keV band

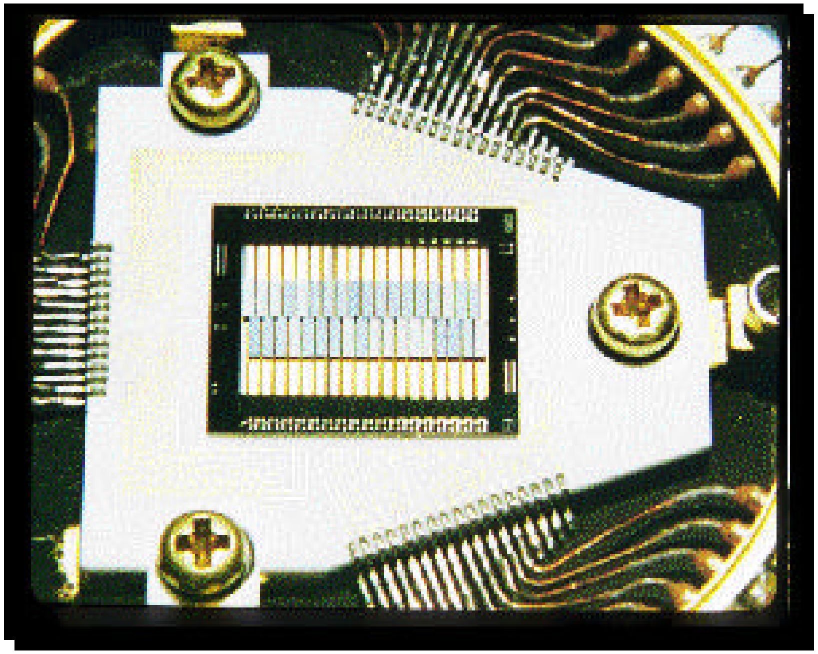
- High quantum efficiency (~99% at FeK)
- Imaging capability commensurate with mirror PSF
  - 2.5' FOV => 30 x 30 array
  - 10' FOV => 120 x 120 array
- Moderate speed for handling counting rates of 1 kHz or more

Current capability is 7-12 eV with 10 x 10 array

Technology developments required to achieve 2 eV resolution include

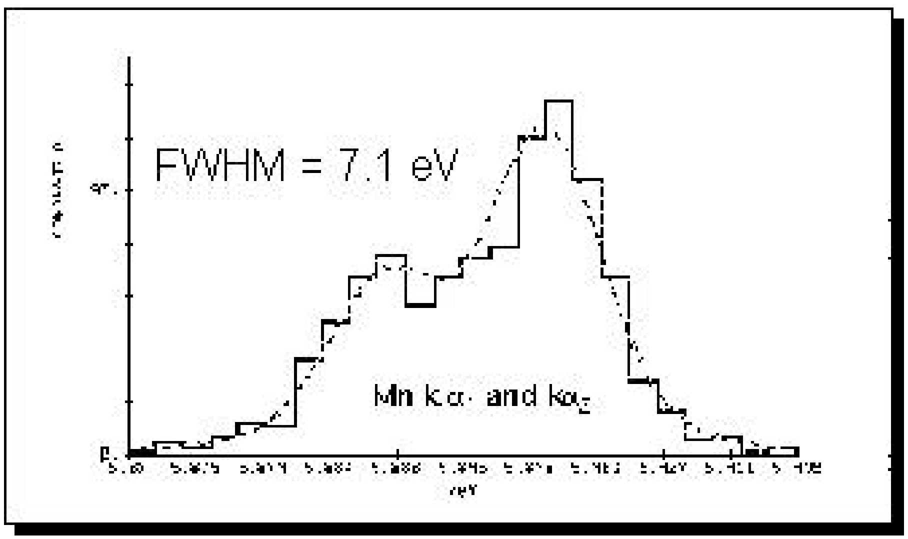
- more sensitive thermometers (transition edge superconductor)
- reduce heat capacity and power dissipation of existing system

Constellation-X Calorimeter Advances



First flight test of Microcalorimeter

- Wisconsin/GSFC rocket flight 06/96
- 36 pixel array operating at 60 mK
- Observation of diffuse X-ray background
- Resolution of 14 eV at 277 eV achieved
- Detection of Sulfur IX and Oxygen VII
- Next flight 8/97 with improved array

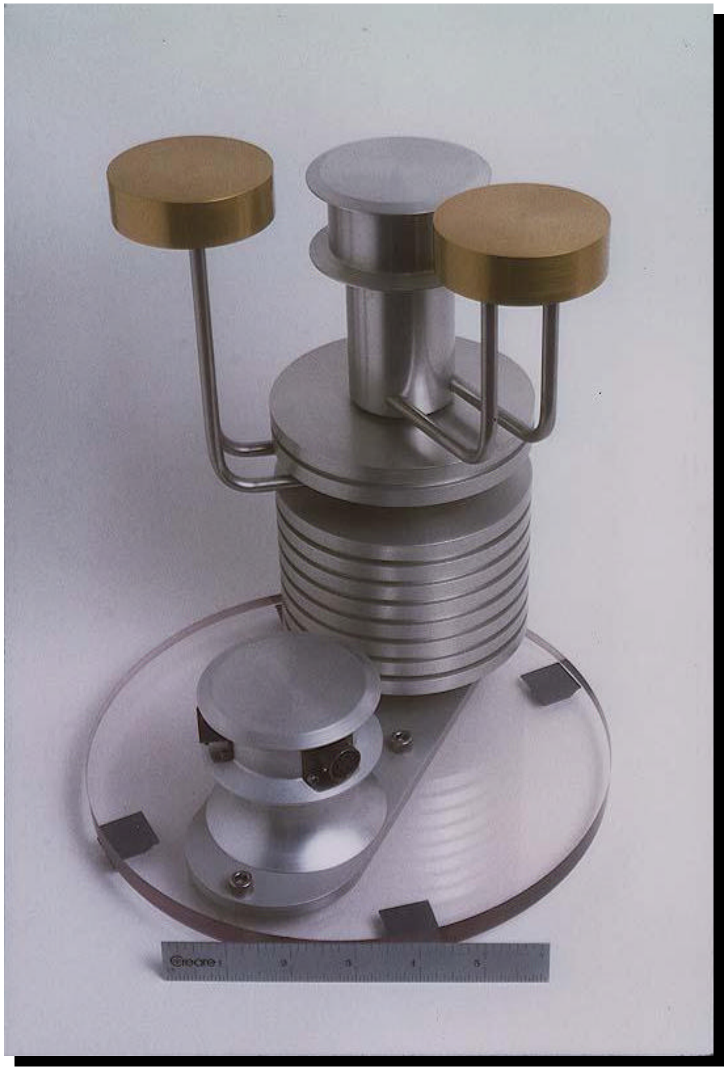


First demonstration of TES Calorimeter at NIST

- Transition Edge Superconduction thermometer
- First result of 7.1 eV in Summer 1996 matches best to date
  - Capable of higher energy resolution
  - Higher counting rates
  - Lower cryogenic heat loads
- Not yet optimized!
  - expect significant improvement

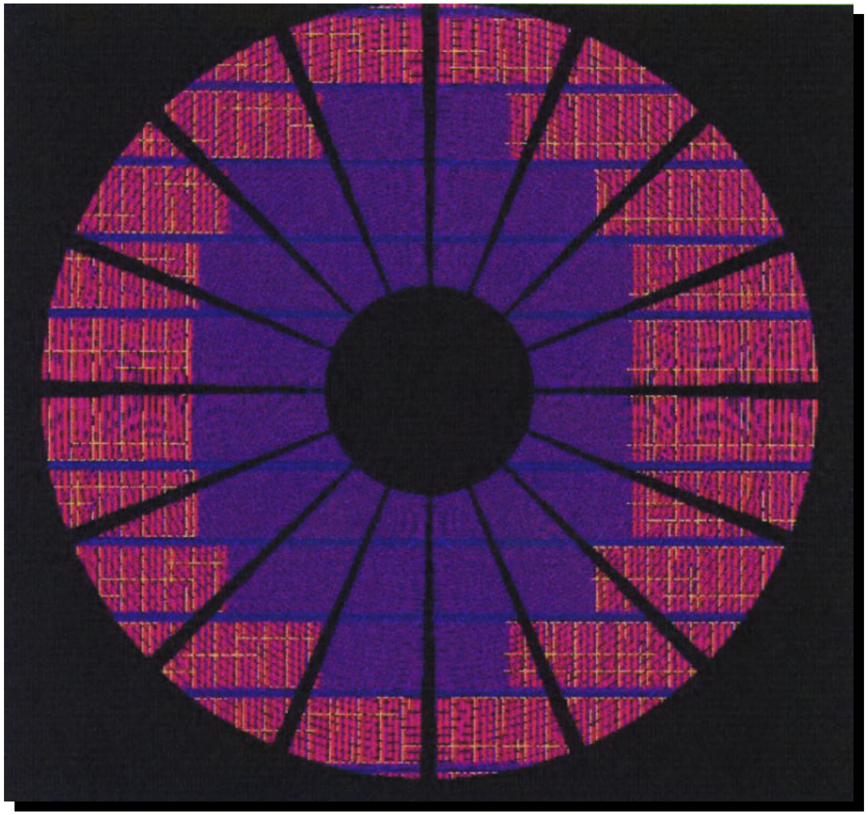
Constellation-X Technology Roadmap
Microcalorimeter Cooling System

Develop long life, low weight, low cost, low vibration cooling systems



- **Required Technologies**
  - Mechanical cryocooler for thermal shields providing 10-100 mW cooling @ 3-5 K
  - Two-stage ADR system to reach 65 mK
- **Investigate alternative technologies**
  - Dilution refrigerator vs ADR
  - Sorption cooler vs Turbo-Brayton cooler
- **Recent progress**
  - Engineering model Turbo-Brayton 5 W, 65 K cooler run for 1.5 years with no degradation; being fabricated for 1999 HST servicing mission
  - 5-50 mW @ 4-10 K breadboard being fabricated with test in early 1998
- **Require funding for two-stage ADR development**

Constellation-X Technology Roadmap
Grating/CCD Spectrometer



- The Grating/CCD spectrometer on Constellation-X will offer unprecedented sensitivity and resolution in the line-rich, low energy (E < 1 keV) X-ray band.
- Effective area more than an order of magnitude better than that of the grating spectrometers on AXAF and XMM will be achieved.
- The design builds on the successful technical heritage of XMM and AXAF.
- Important new technology developments will include
  - Significant reduction in the mass per unit area of the grating array
  - Improved diffraction efficiency and reduced scattering from the individual grating elements
  - Significant reduction in the power consumption and total mass of the CCD and their associated read-out electronics
  - Improved low energy quantum efficiency in the CCDs

Constellation-X Technology Roadmap
Hard X-ray Telescope: Optics

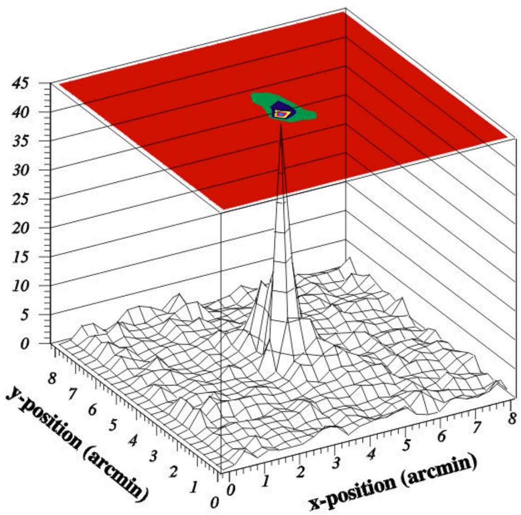
Primary Approach - Segmented shells

- **Approach drawn from *ASCA, ASTRO-E, SODART***
- **Epoxy replicated foils or thermally-formed glass substrates:**
  - Mass ~ 100 kg achievable
  - Measured surface quality - 3.7 Å glass, 5.5 Å foils meets requirements

Required technical development

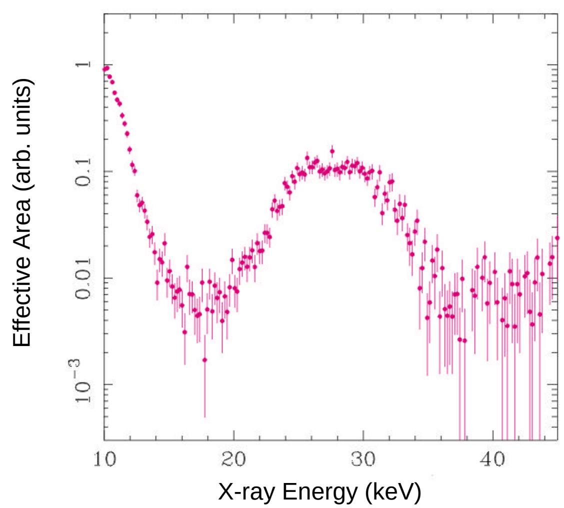
- **Demonstrate coating without distortion**

Pt/C Foil Optic and
CdZnTe Strip Detector Mosaic (20-40 keV)



GSFC/Nagoya

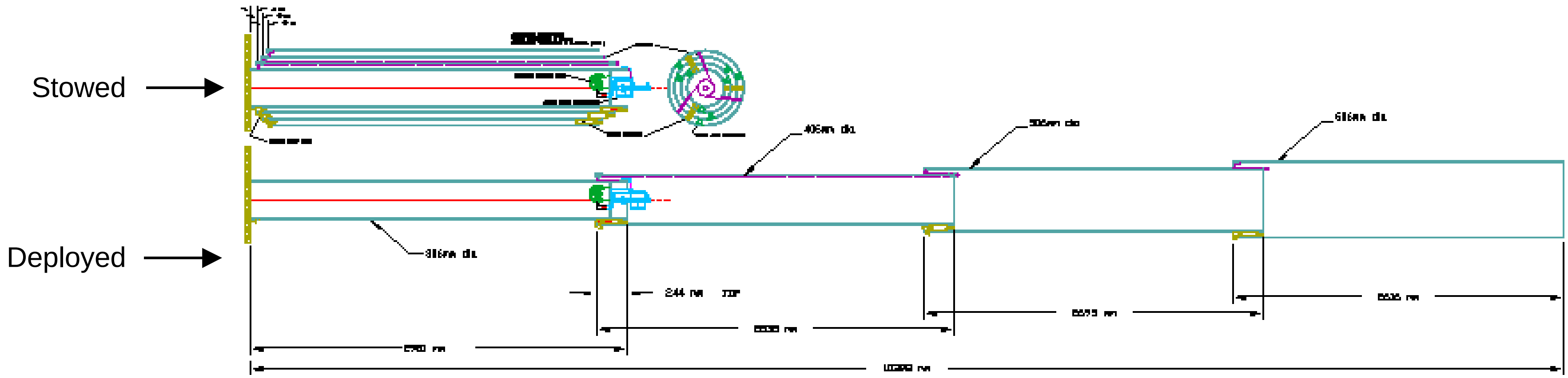
Effective Area



- Image at 30 keV achieved in August 1997 using Pt/C multilayer on an epoxy replicated foil mirror shell at GSFC/Nagoya -- 30 layer pairs, 0.13 micron thick with no distortion of foil due to stress
- W/Si multilayer on curved glass at Caltech/Columbia -- 200 layer pairs, 0.66 micron thick with acceptable stress
- Balloon flights planned in 1999

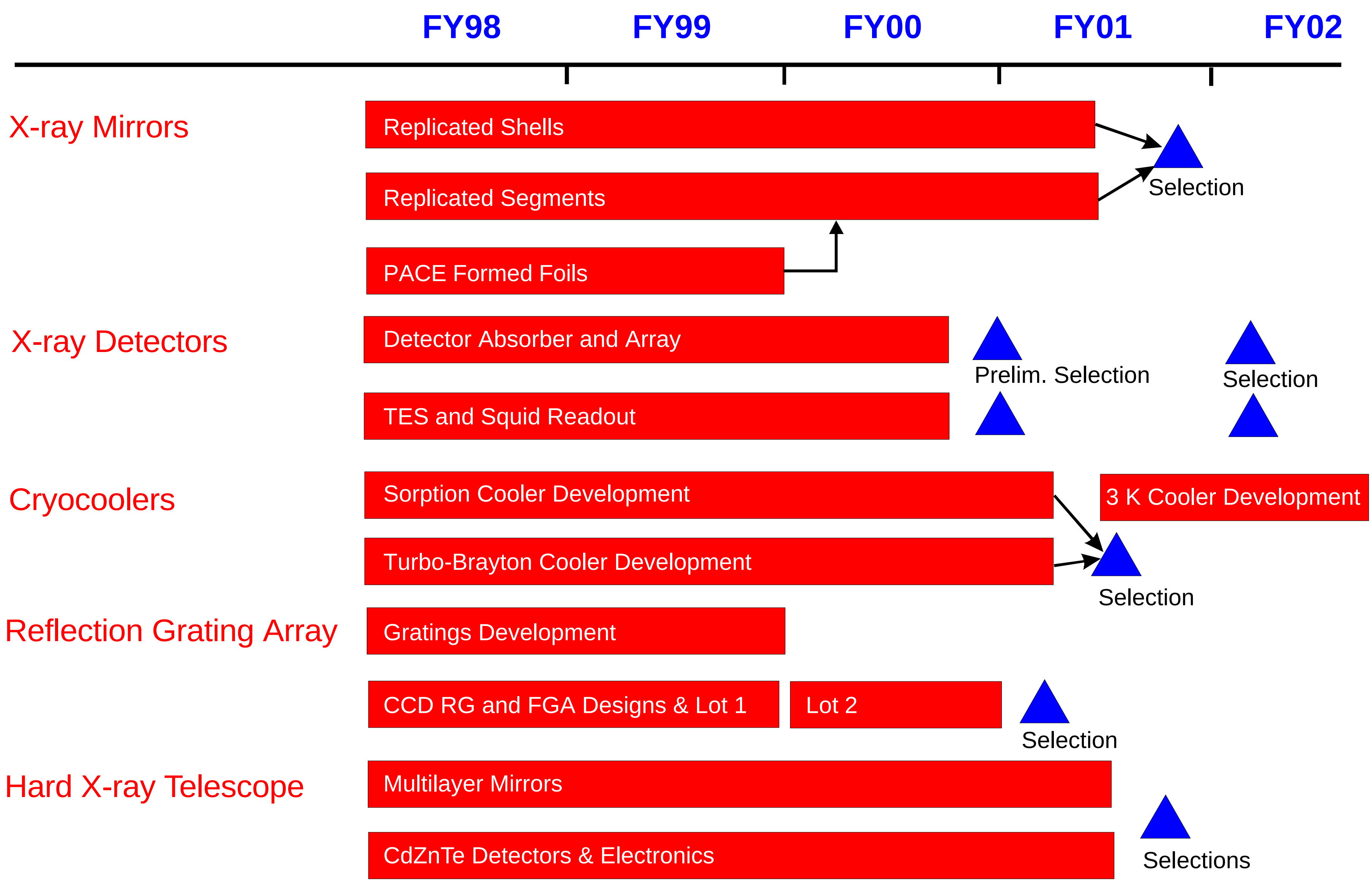
The Constellation-X Extendible Optical Bench (EOB)

EOB provides the platform or support between the mirrors and the detectors and maintains their respective alignment for the mission



- Constellation-X Requirements
  - Provide for a focal length of approximately 8.5 meters with a stable structure (~ 1 mm) both mechanically and thermally
  - EOB deployable to utilize Delta II-class launch vehicle
  - Provide light tight protection to SXT and Grating/CCD
- EOB Development Status
  - Awarded partial funding through GSFC Directors Discretionary Fund in 97
  - Optical alignment sensing system demonstrated in the lab using off-the-shelf components
  - Vendors have reviewed baseline tube structures and confirm approach is feasible
  - Next step is to produce an engineering unit to demonstrate the system performance

Constellation-X Technology Roadmap



X-ray Observatories Timeline

Constellation-X

Upcoming Missions:

AXAF
Spectrum XG
XMM
Astro-E

Current Missions:

ROSAT
ASCA
RXTE
BeppoSAX

1996 1998 2000 2002 2004 2006 2008 2010

The Outlook for the Constellation X-ray Mission

Summer of 1998...

- Technology development efforts have begun in earnest
- Mission concept study has demonstrated mission feasibility to next level of detail
- Cost estimates and Phase B/C/D schedule have been refined
- Acquisition strategy has been developed
- Outreach program underway

Summer of 2002...

- Phase B is halfway complete
  - Mission contractor has been selected
  - Systems Requirements Review has just taken place
- Technology developments required for Constellation-X are complete
  - Selections made between competing technologies

International Collaboration

International participation in the Constellation X-ray Mission is encouraged

- Too soon to make specific agreements on contributions until the technology is selected
- Current emphasis on contributing to the technology development program

Current arrangements and teaming:

- Osservatorio Astronomico di Brera (Italy)/SAO/MSFC developing lightweight replicated shell optics
- Nagoya University (Japan)/GSFC: Multilayers for HXT
- Danish Space Research Institute/CalTech: Multilayers for HXT
- MSSL (UK)/GSFC: Two-stage ADR
- Leicester University (UK)/GSFC: Microchannel plates for HXT

Summary

The *Constellation* X-ray Mission traces the evolution of the Universe from origins to endpoints

- the production and recycling of elements
- the origin and evolution of black holes

Investment now beginning to develop advanced technology to enable the mission

- assembly line production of lightweight, high performance optics, detectors, coolers, and spacecraft
- Multi-satellite concept is low-risk

Facilitates ongoing science-driven, technology-enabled extensions*:*

- spatial resolution,
- collecting area,
- energy bandwidth, and
- spectral resolution

http://constellation.gsfc.nasa.gov